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MODEL 3300B
DIGITAL MULTIMETER

HICKOK ELECTRICAL INSTRUMENT COMPANY
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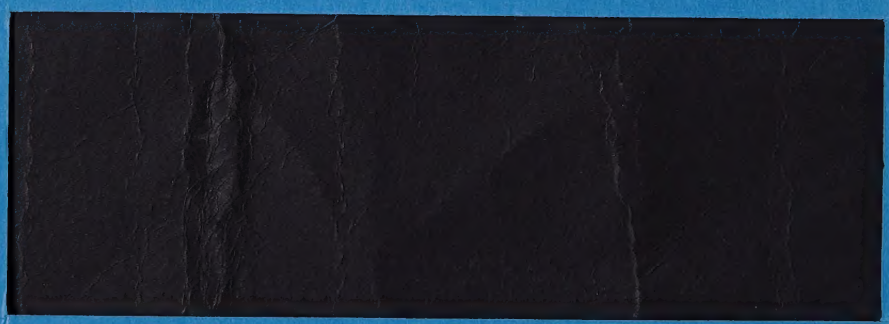

MODEL 3300B
DIGITAL MULTIMETER

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HICKOK

WARRANTY

The Hickok Electrical Instrument Company warrants this instrument of its manufacture to be free from defects in material and workmanship for one year (12 months) from the date of original purchase. Any instrument found to be defective during this period may be returned, transportation prepaid, to the factory for repair, or at our option, replaced without charge.

This warranty does not apply to any of our products which have been repaired or altered by unauthorized persons, or which have been subject to misuse, negligence, or accident, or which have had the serial number altered, effaced or removed. Neither shall the warranty apply where a warranty registration card has not been properly completed and returned to us promptly after purchase. This warranty is in lieu of all other warranties whether expressed or implied.

RETURNING EQUIPMENT FOR REPAIR

Before returning any equipment for service, the factory must first be contacted, giving the nature of the trouble. Instructions will then be given for either correcting the trouble or returning the equipment. Upon authorization, this equipment should be forwarded directly either to the Hickok factory address at 10514 Dupont Avenue, Cleveland, Ohio, 44108, or to a designated service station in your locality.

19120-158

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SECTION I
GENERAL INFORMATION

The Model 3300B Digital Multimeter provides 27 ranges covering ac and dc volts, ac and dc current and resistance. The multimeter may be operated from a 115 or 230 volt* ac line or from an internal rechargeable battery pack. The batteries permit measurement with complete isolation from power line interference (infinite common mode rejection). Approximately 24-hour battery life allows operation in field locations for extended periods of time. The multimeter may also be operated from the ac power line while the batteries are being recharged.

The bright fluorescent digital display consists of seven-segment numerical indicators which provide a maximum display of 1999. The display features include non-blinking buffered readout, an automatic polarity indicator, automatically positioned decimal point and blinking overrange indication. The reading rate is twice per second. The blinking overrange indication occurs when the readings exceed 1999.

*See Schematic diagram for 230 volt connections.

Operator convenience and safety have been stressed in the design of the model 3300B multimeter. For operator protection on high voltage measurements the case of the 3300B is completely isolated from the input terminals and contains no metal parts. The case is high impact resistant plastic with shock mounted printed circuit boards. The input terminals and internal circuitry may be elevated up to 1500 volts from line ground. A color coded front panel is provided for ease in selection of the 27 ranges. A high input impedance minimizes erroneous readings due to loading the circuit under test. The 3300B multimeter incorporates circuitry which prevents damage to the unit in case of overloads or improper switch settings.

Rugged construction, wide temperature operating range and convenience of operation make the 3300B multimeter ideal for field applications as well as for laboratory and production line use.

SECTION II
SPECIFICATIONS

FUNCTIONS

AC and DC Volts

AC and DC Current

Resistance

RANGES

AC and DC Volts

Range	Reading	Resolution
100 mV	000.0 to 299.9 mV	100 microvolts
1 V	0.000 to 2.999 V	1 millivolt
10 V	00.00 to 29.99 V	10 millivolts
100 V	000.0 to 299.9 V	100 millivolts
1 kV*	0.000 to 1.500 kV	1 volt

* Product of volts and frequency $\leqq 10^7$, 1000 volts rms max. input

AC and DC Current

Range	Reading	Resolution	Insertion Resistance
100 μA	000.0 to 299.9 μA	100 nanoamperes	1 KΩ
1 mA	0.000 to 2.999 mA	1 microampere	100 Ω
10 mA	00.00 to 29.99 mA	10 microamperes	10 Ω
100 mA	100.0 to 299.9 mA	100 microamperes	1 Ω
1A	0.000 to 2.999 A	1 milliampere	0.1 Ω

OHMS

Ranges	Reading	Resolution	Polarity Lo	Polarity Hi	Max. Current	Power in Rx @ full Scale
100 Ω	000.0 to 199.9 Ω	0.1 Ω	-	+	250 μA	6.25 μW
1k Ω	0.000 to 1.999 Ω	1.0 Ω	-	+	25 μA	0.625 μW
10k Ω	00.0 to 1.999 Ω	10 Ω	-	+	2.5 μA	0.0625 μW
100kΩ	000.0 to 199.0 Ω	100 Ω	-	+	0.25 μA	0.00625 μW
1MΩ	0.000 to 1.999M Ω	1k Ω	+	-	250 μA	6.25 μW
10M Ω	00.00 to 19.99M Ω	10k Ω	+	-	25 μA	0.625 μW
100MΩ	000.0 to 199.9M Ω	100k Ω	+	-	2.5 μA	0.0625 μW

Maximum open circuit voltage: 2.5V

OVERLOAD PROTECTION

AC Volts	Ohms
250 V on 100 mV range 1000 V on all other ranges	100V on 100 Ω range 250 V on all other ranges
DC Volts	**Current**
1000 V on 100 mV range 1500 V on all other ranges	10 times full scale on all ranges

OPERATING TEMPERATURE RANGE

0° to 50° C

ACCURACY

Function	Range	Accuracy at 20° C to 30° C	Temperature Coefficient 0-19° C 31-50° C
DC Volts	100mV to 1500V	±0.1% of reading, ±0.1% of range	150 ppm/C°
AC Volts	100mV to 1000V		
	22Hz to 50 Hz (Max. overrange 100%)	±1.5% of reading, ±0.2% of range	200 ppm/C°
	50Hz to 50kHz	±0.5% of reading, ±0.2% of range	200 ppm/C°
	50kHz to 100kHz	±1.0% of reading, ±0.2% of range	200 ppm/C°
NOTE: Volts x freq. product must not exceed 10^7			
DC Amps	100μA to 10mA	±0.2% of reading, ±0.1% of range	200ppm/° C
	100mA & 1A	±0.5% of reading, ±0.1% of range	200ppm/° C
AC Amps	100μA to 10mA		
	22Hz to 50Hz	±1.5% of reading, ±0.1% of range	200ppm/° C
	50Hz to 50kHz	±0.5% of reading, ±0.1% of range	200ppm/° C
	50kHz to 100kHz	±1.0% of reading, ±0.1% of range	200ppm/° C
	100mA to 1A	Add 0.5% of reading	200ppm/° C

OHMS

100Ω thru 100K Readings ≦ 110% of Full Scale 1M thru 100M Readings ≦ 200% of Full Scale	0.3% of range ± 1 digit except 100M which is 0.6% of range ± 1 digit
100Ω thru 100K Readings ≧ 110% of Full Scale and ≦ 200% of Full Scale	±1.25% of Reading ± 1 digit

200 ppm/C°

NOTE: Add 0.1% of range to all accuracy specs. when operating during battery charge.

INPUT ISOLATION FROM GROUND

Infinite when operated on batteries.

1500 volts peak when line operated or with batteries charging.

INPUT IMPEDANCE AT PROBE TIP

dc: 11 megohms/5pF.

ac: Approx. 1000 MΩ/75 pF.

COMMON MODE REJECTION (with 1k ohm source unbalance)

Battery operation: Infinite

Line operating or on recharge: 120 dB at 60 Hz, 90 dB at 1 kHz.

NORMAL MODE REJECTION

50 dB at 40 Hz

60 dB at 60 Hz

70 dB at 120 Hz

DISPLAY

7-segment numerical indicators

non-blinking (buffered)

Maximum display of 2999

Automatically positioned decimal point

Automatic polarity indicator

Out-of-range indication

Sample rate: two per second

OPERATING POWER REQUIREMENTS

a. Internal, rechargeable battery supply.

b. Power Line supply: 115 or 230 Volts ac ±10%. (See schematic wiring diagram for 230 volt connections.)
50 to 400 Hz
5 Watts

DIMENSIONS

8 in. high x 5-7/8 in. wide x 4 in. deep.

WEIGHT

Model 3300B: 6-1/4 pounds

OPERATING INSTRUCTIONS

GENERAL

The Model 3300B multimeter is designed to operate from either an internal battery pack or a 115 or 230 volt*, 50-400 Hz ac power source. The rechargeable nickel-cadmium batteries permanently installed in the unit recharge directly from the power line when the power cord is plugged into an ac outlet. Battery charging is indicated by a sub-panel lamp above the display.

A supply check position (CHK) is incorporated in the multimeter to monitor the state of the batteries. To perform this operation, set the function switch to CHK and the range switch to any volts position; the readout will then display a number proportional to the charge state of the batteries. If the number is greater than 1000 the multimeter may be operated. If the number is less than 1000 the batteries must be recharged (Refer to Fig. 1 for approximate hours of operation remaining versus CHK reading).

*See Schematic diagram for 230V connections.

AC OPERATION

The multimeter may be operated while plugged into an ac power source. When operated in this mode the unit receives power from the batteries while the batteries are being charged from the ac power source. The charging circuit supplies approximately 30% more power than necessary to operate the unit such that the batteries may be charged during operation.

CAUTION

Whenever the multimeter is operated on ac power, the LO input must not be elevated more than 1500 volts ac peak plus dc as referenced to the ac power source ground.

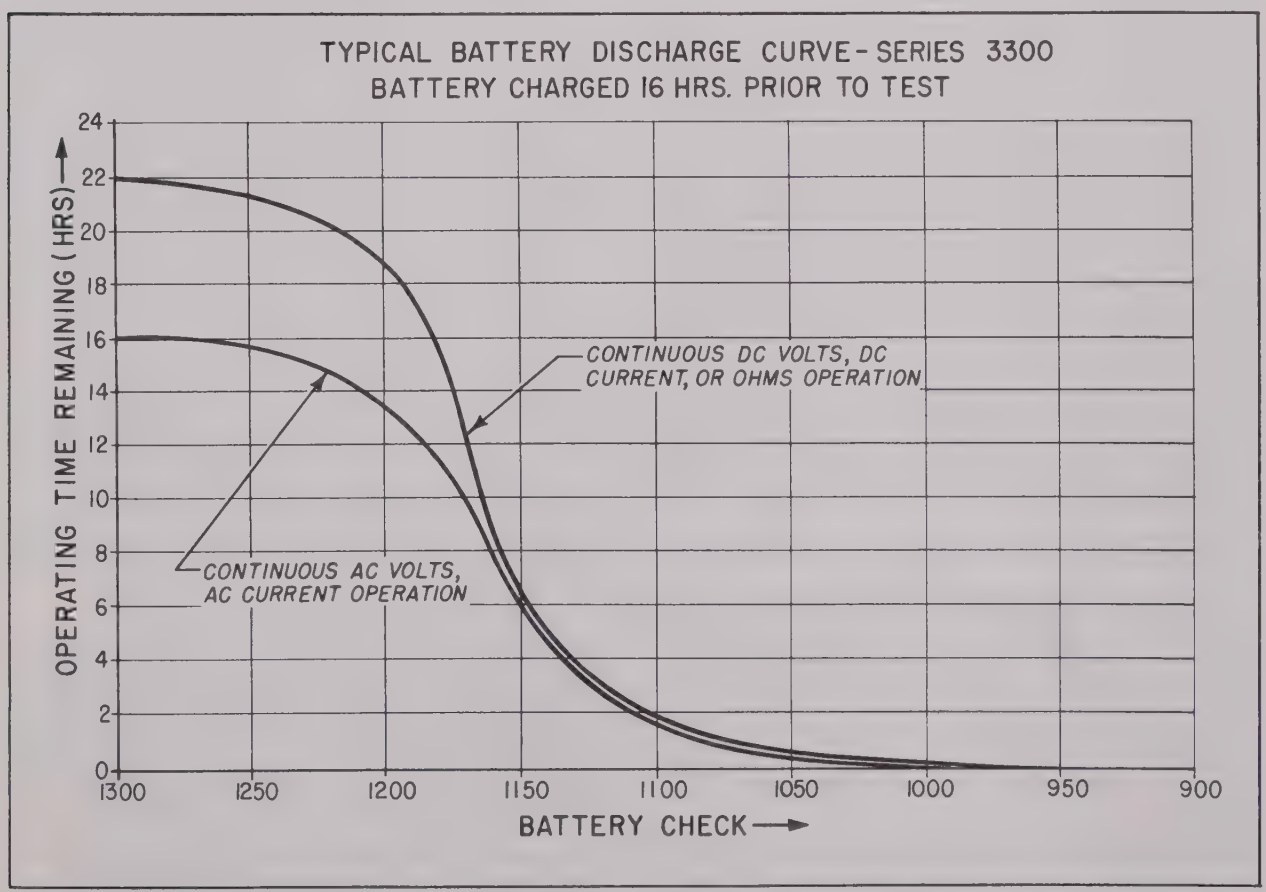


Figure 1. Typical Battery Discharge Curve, Series 3300

The following paragraphs describe the operation of the multimeter.

To turn the instrument on set the function switch to any position except OFF. This will activate the display showing that the multimeter is energized and ready for use. It is recommended that approximately five minutes warm up be allowed for stabilization of the circuitry.

FRONT PANEL

The front panel is color coded for ease of operation. Each function has a characteristic color and the ranges for that function have the same color. AC and DC Volts functions are red and the range switch has five red ranges from 100mV through 1kV. OHMS function is green and the range switch has 7 green ranges from 100 Ω through 100 MΩ. AC I and DC I current functions are yellow and the range switch has 5 yellow ranges from 100μA through 1 A.

A blue pilot light is provided to indicate when the batteries are being charged. The state of the batteries may be checked in the CHK position on the multimeter.

MEASUREMENTS

Five types of measurements can be made with the Model 3300B equipment. They are: ac volts, dc volts, ac current, dc current, and ohms. Each type of measurement is selected by setting the function switch to the proper function and the range switch to the desired range.

The function switch selects the type of measurement to be made. The range switch sets the full scale value of the measurement. Each position on the range switch is labeled in the units to be measured and the full scale value of that range. As an example, there are three positions labeled "V". The unit is volts, the three positions are 1 volt, 10 volts, and 100 volts full scale. The decimal point is automatically positioned in the display. In all functions, if an unknown quantity is to be measured the range switch should be set to the highest range and then switched to lower ranges as required for a three or four digit reading.

DC VOLTS

DC voltage measurements are made by setting the function switch to DC V and the range switch to the desired voltage range. The LO input terminal is then connected to the point in the circuit under test that is nearest ground and the HI input is connected to the voltage to be measured relative to that point. The LO input should never be elevated more than 1500V above ac power line third wire ground.

The Model 3300B incorporates circuitry which enables it to withstand overloads up to 1000 volts on the 100 mV range and 1500 volts on all other ranges.

CAUTION

No dc voltage measurement above 1500 volts may be made without the use of a high voltage probe. Probes are available that extend the range to either 15kV or 30kV.

AC VOLTS

AC voltages are measured by setting the function switch to AC V and the range switch to the desired range. When switching to the AC V function allow several seconds for the ac/dc converter to stabalize before making the measurement. The HI and LO inputs are used in the same fashion as in dc volts. AC functions are overload protected as specified in Section II.

CAUTION

The absolute maximum input voltage permitted between the HI and LO inputs is 1000 volts rms. Also, the input voltage times frequency product must not exceed 10^7.

OHMS

Resistance is measured by setting the function switch to OHMS and the range switch to the desired range. In all ohms ranges the HI jack is positive and in all megohms ranges the LO jack is positive. Maximum open circuit voltage is 2.5 volts on all ranges. When the multimeter is set up for ohmmeter use, the display will blank when not measuring a resistance or when the resistance is greater than 1999 on the range selected. The ohmmeter section is protected for high voltage application as specified in Section II.

A unique feature of the Model 3300B ohms ranges is that semiconductors may be forward biased and thereby checked for proper P-N junction behavior.

The voltage across the unknown resistor in ohms and k ohms varies from zero volts at zero readings to approximately 24mV at full scale readings. This voltage being the results of a voltage divide formed by an internal precision resistor and the unknown external resistor. The multimeter measures the voltage across the unknown resistor and is calibrated to read in resistance. An input voltage greater than 48mV (2Xf.s.) will cause the multimeter to overrange.

In megohms the voltage across the unknown resistor varies from zero volts at zero reading to approximately 2.4 volts at full scale (2.4V-0.024V). As discussed under functional operation, the megohm ranges are inverted such that the multimeter actually measures the voltage across the internal precision resistor (proportional to 1/Rx) and converts this to indicate the value of the unknown resistor directly.

Therefore, measurements on the 100 ohms through the 100 k ohms range produce 48mV or less across the unknown resistor for an in range reading and measurements on the 1 megohm through 100 megohm

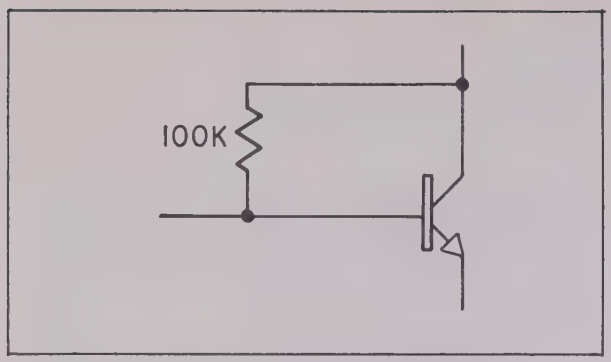


Figure 2. Transistor Circuit Ohmmeter Measurements

range produce 2.4V or less across the unknown resistor for an in range reading.

The 100k resistor shown above will measure 100k ohms on the 100k Ω range no matter which polarity is used since 24mV will not forward bias the base - collector of the NPN transistor. However, on the 1M Ω range the multimeter will read 0.100 megohm when the base-collector is reverse biased (HI is negative, LO is positive) and approximately 0.003 megohm when the transistor is forward biased. The forward bias of a silicon P-N junction, 0.600 volts, is equivalent to approximately 3% of range on all megohm ranges.

Note that if a diode or transistor alone is being checked on the megohm ranges the reading obtained will be overrange (open circuit), when the junction is reverse biased and 3% of full scale (003) when the junction is forward biased. Reverse leakages at 2.4 volts may be measured if below 200 megohms.

DC CURRENT

DC current is measured by setting the function switch to DC I and the range switch to desired current range. Insertion loss is as specified in Section II. The current shunts are designed to withstand a 10 times full scale overload.

AC CURRENT

AC current measurement is similar to dc current except that the function switch is set to AC I. When switching to AC I allow several seconds for the ac/dc converter to stabilize before making the measurement. Overload is the same as for dc current.

CAUTION

Overloads in excess of 10 times full scale may permanently damage the precision current shunts.

Elevated voltage and current measurements may be made in both battery and ac line operation. However, the total voltage between the LO input and third wire ac power line ground must not exceed 1500 volts ac peak plus dc. Breakdown between internal circuitry and the power supply transformer primary and between internal circuitry and outer case necessitate this limitation. Extreme caution is always necessary when high voltages are present.

SECTION IV
MINIMIZING EXTERNAL SOURCES OF ERROR

The multimeter is an exceptionally accurate and stable instrument. Operator convenience and measurement simplicity have been stressed throughout. Unique circuit design, special compensation techniques, and stable components have eliminated the necessity for front panel zero or calibration controls. If inaccuracies are encountered, the measurement setup external to the unit should be carefully checked.

The multimeter will measure dc volts and current, ac volts and current, and ohms to a high degree of accuracy. Attention to the details outlined in the following paragraphs will minimize external sources of error and help the operator to achieve maximum accuracy.

LOADING ERRORS - AC

The ac input impedance of the multimeter is designed to be as high as is practically possible. However, when voltage measurements are required to the full accuracy of the instrument the internal impedance of the voltage source should be considered.

AC INTERFERENCE ON DC MEASUREMENTS

It is often necessary, or convenient, to measure dc voltages in the presence of large ac voltages. This is most often the case when measurements are taken on equipment which is in normal operation; for example, measuring the collector voltage of a large signal pulse amplifier stage, or grid bias shifts in class B amplifiers. Further, unshielded high impedance circuits are subject to pickup of large voltages from nearby electrostatic fields, such as the 60 Hz line, fluorescent lights, etc. For these reasons the multimeter is designed to accept large ac voltages across its input terminals and still give an accurate indication of the dc component.

This ability to discriminate between ac and dc signals is an outstanding feature of this instrument. It is accomplished by two means: first, the input voltage is filtered by a conventional R-C network; then, the integrator amplifier, with a ramp peak of 10 volts and an integration time of 100 milliseconds, eliminates the remaining fluctuations.

The multimeter is specified to have, for example, a 60 dB rejection of 60 Hz interference. This means that the apparent reading error (which may be either plus or minus) will be 1/1000 (one thousandth) of the impressed ac value. To illustrate, if we add one volt rms of 60 Hz ac to one-half volt dc, we will have an extra error of 0.001 volt. Consequently, our readings could shift by ± 2 digits. So, as a result of adding one volt 60 Hz ac, we have added 0.001 volt of uncertainty to our final reading - a very small error. However, it is preferable to keep the ac voltages within the limits allowed for ± 1 digit of error.

DIELECTRIC ABSORPTION

Dielectric absorption is associated with insulating materials and is inherent in their chemical structure. This multimeter has been carefully designed to reduce this effect within itself, but it may occur in the external circuitry. After a capacitor has been charged and then shorted out, a small percentage of the original voltage will reappear across it after a time, thus requiring a second discharge. The capacitor may persist for several hours in generating these small voltages. Thus, care should be taken when a high voltage measurement is followed by a very low voltage measurement in a circuit with questionable dielectric absorption.

LOADING ERRORS - DC

Whenever voltage measurements are required to the full accuracy of the multimeter, the internal impedance of the voltage source should be considered. The input impedance of the multimeter was designed to be as high as possible, but if the internal impedance of the voltage source exceeds 5k ohms it must be taken into account. The input impedance of the multimeter is 11 megohms ± 0.1%. Consequently, an 11k ohms source impedance will cause the unit to read 0.1% low; a 110k source impedance will cause a 1% drop in reading. Corrections for loading can be made when the source impedance is known by applying the following formula:

$$\text{True voltage} = \text{multimeter reading} + \text{multimeter reading} \times \left(\frac{\text{source impedance in ohms}}{11 \times 10^6} \right)$$

By using the formula, loading errors can be kept below 0.1% for source impedances as high as 10^7 ohms.

ENVIRONMENT

A number of possible sources of error are introduced by severe environments. The multimeter is designed to eliminate as many of these as possible. Both temperature and humidity factors have been taken into account. The unit's specified accuracy will be retained over a temperature range of 20°C to 30°C. Humidity effects have been reduced by extremely careful treatment of insulating surfaces. If errors are encountered which can only be attributed to environmental changes, these will most likely be found in the external measurement setup.

Corrosive atmospheres, particularly when the humidity is high, can cause large leakage currents. The multimeter is totally enclosed and should not be opened or otherwise exposed to industrial atmospheres. The test setup as well should be kept as clean as possible. In the event of difficulties, clean, dry Freon TF mixed with Dow-Corning Silicone Oil DC 200 in a ratio of 50:1 should be used to carefully clean contaminated binding posts, switches or other leakage paths.

OHMS MEASUREMENTS

AC rejection on the ohms ranges is the same as is specified for the other ranges: a 60 Hz signal in excess of 60 dB will cause a fluctuation in the reading (input sensitivity is 25mV/1000 counts). The maximum sensitivity of the ohmmeter circuit is 0.1 ohms per digit on the 100 ohm range. As in any low range ohmmeter, contact resistance can become a significant portion of the total resistance being measured and must be considered. Careful attention to circuit connections can minimize these errors. High impedance measurements, in the megohms region, are subject to pickup of large voltages from nearby electrostatic fields. Careful attention to lead length, component placement and shielding will minimize pickup on high resistance measurements. External leakage paths through insulation material associated with the resistance under measurement can also cause error. In effect, these leakage paths form resistance paths in parallel with the true resistance, thus reducing the value. All of these are external effects and should be taken into account whenever there is doubt in the reading.

HARMONIC DISTORTION

Average reading instruments such as this multimeter are calibrated in rms for pure sinusoidal inputs. However, in the presence of harmonic distortion, average reading instruments will deviate from the true rms value as a function of the relative amplitude, phase, and order of the harmonic with respect to the fundamental. Table 1 provides error limit values for distortion levels of 0.1% for the second and third order harmonics.

Harmonic Number	Form of Distortion Relative to $\sqrt{2}\sin\omega t$ Fundamental	Composite Waveform: Average Meter	Composite Waveform: RMS Value	Error Limit	Average meter indication limit of error vs. true rms (in %): Distortion Level 0.1%	0.3%	1%	2%	5%	10%
2	$\pm a\sqrt{2}\cos 2\omega t$	$1 + \frac{a^2}{2} - \frac{5}{8}a^4$	$1 + \frac{a^2}{2} - \frac{a^4}{8}$	Minimum Negative	0.00	0.00	0.00	0.00	0.00	-0.01
	$\pm a\sqrt{2}\sin 2\omega t$	1	$\sqrt{1 + a^2}$	Maximum Negative	0.00	0.00	-0.01	-0.02	-0.12	-0.50
3	$a\sqrt{2}\sin 3\omega t$	$1 + \frac{a}{3}$	$\sqrt{1 + a^2}$	Maximum Positive	+0.03	+0.10	+0.33	+0.65	+1.54	+2.82
	$-a\sqrt{2}\sin 3\omega t$	$1 - \frac{a}{3}$	$\sqrt{1 \quad a^2}$	Maximum Negative	-0.03	-0.10	-0.34	-0.68	-1.79	-3.81

Notes: a = fractional distortion level = $\frac{\%\text{ distortion}}{100}$

Percentage error (average meter vs. true rms) = $\frac{E_{\text{indicated average meter}} - E_{\text{rms}}}{E_{\text{rms}}} \times 100\%$

Percentage error (average meter vs. fundamental = $(E_{\text{indicated average meter}} - 1) \times 100\%$

Percentage error (rms meter vs. fundamental) = $\frac{E_{\text{rms}} - E_{\text{fundamental}}}{E_{\text{fundamental}}} \times 100\% \approx + \frac{a^2}{} \times 100\%$

The following three rules apply:

Rule 1: An n^{th} order odd harmonic may, depending upon phase, increase or decrease the average value by as much as 1/n times its relative amplitude, for distortion up to (100/n)%. An average-detecting meter indication is in error by this shift corrected by the amount of the distortion's effect on the true rms value.

Rule 2: An even harmonic that is in phase with the fundamental, for distortion up to (100/n)%, does not affect the average value.

Rule 3: An even harmonic in quadrature with the fundamental increases the average value in approximately the same manner as it increases the rms value.

Table 1. Range of Average-Detecting Meter Deviation from True RMS in the Presence of Harmonic Distortion

SECTION V
THEORY OF OPERATION

The multimeter utilizes a triple segment sequence time ratio integration technique that converts a dc input voltage to a number of pulses. The number of pulses is directly related to the dc input voltage and is internally counted and displayed. The cycle time is approximately one half second. At the beginning of each cycle an internally generated reset pulse resets the counters to zero and the system again samples the input dc voltage. The actual input sample time is approximately 100 milliseconds and the remaining 400 milliseconds is used for comparison and self-zeroing.

All functions on the multimeter use this dc to count conversion. In ac volts, alternating current, direct current, and ohms, the quantity being measured is converted to a dc voltage. This dc voltage is then measured and displayed.

The analog-to-digital conversion is accomplished through the use of a basic principal of electricity.

In figure 3, the expression for the voltage across the capacitor for time after the switch is closed is:

$$Vab = \frac{1}{C} \int_0^t idt \qquad (1)$$

It is obvious from the circuit that the capacitor will charge to the battery voltage at a rate determined by R and C. Equation (1) is the integral form for the charge voltage as a function of time (assuming no charge on the capacitor prior to switch closure). The current, i, in equation (1) is a time varying current and the solution of the equation yields the well-known exponential charge curve for the voltage across C.

However, if i is made constant by use of a constant current generator, large R, or other means, then the solution of equation (1) is a linear ramp voltage dependent only on time.

$$Vab = \frac{1}{C} \int_0^t idt$$

$$Vab = \frac{1}{C} \int_0^t Idt$$

$$Vab = \frac{I}{C} (t) \qquad (2)$$

Equation (2) illustrates the fact that the voltage across C, when I is constant, is a ramp voltage whose slope is dependent on I and whose magnitude varies with time. Therefore, since time is the only variable, the ramp voltage is linear, i.e., not exponential, if C is a perfect capacitor.

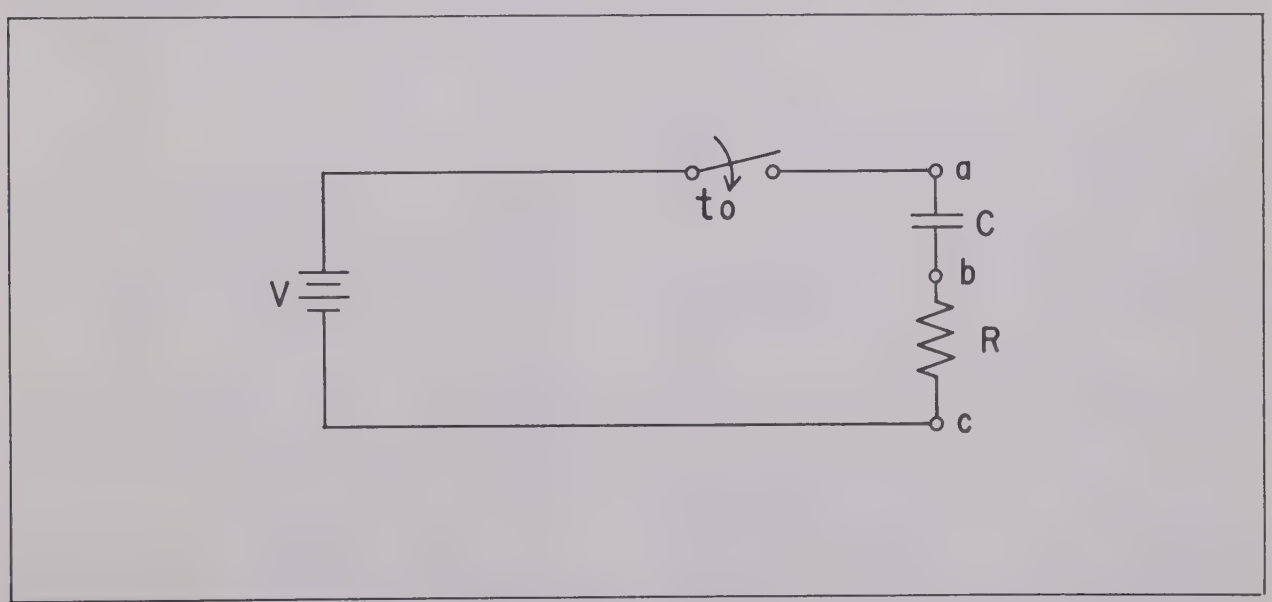


Figure 3. Basic RC Network

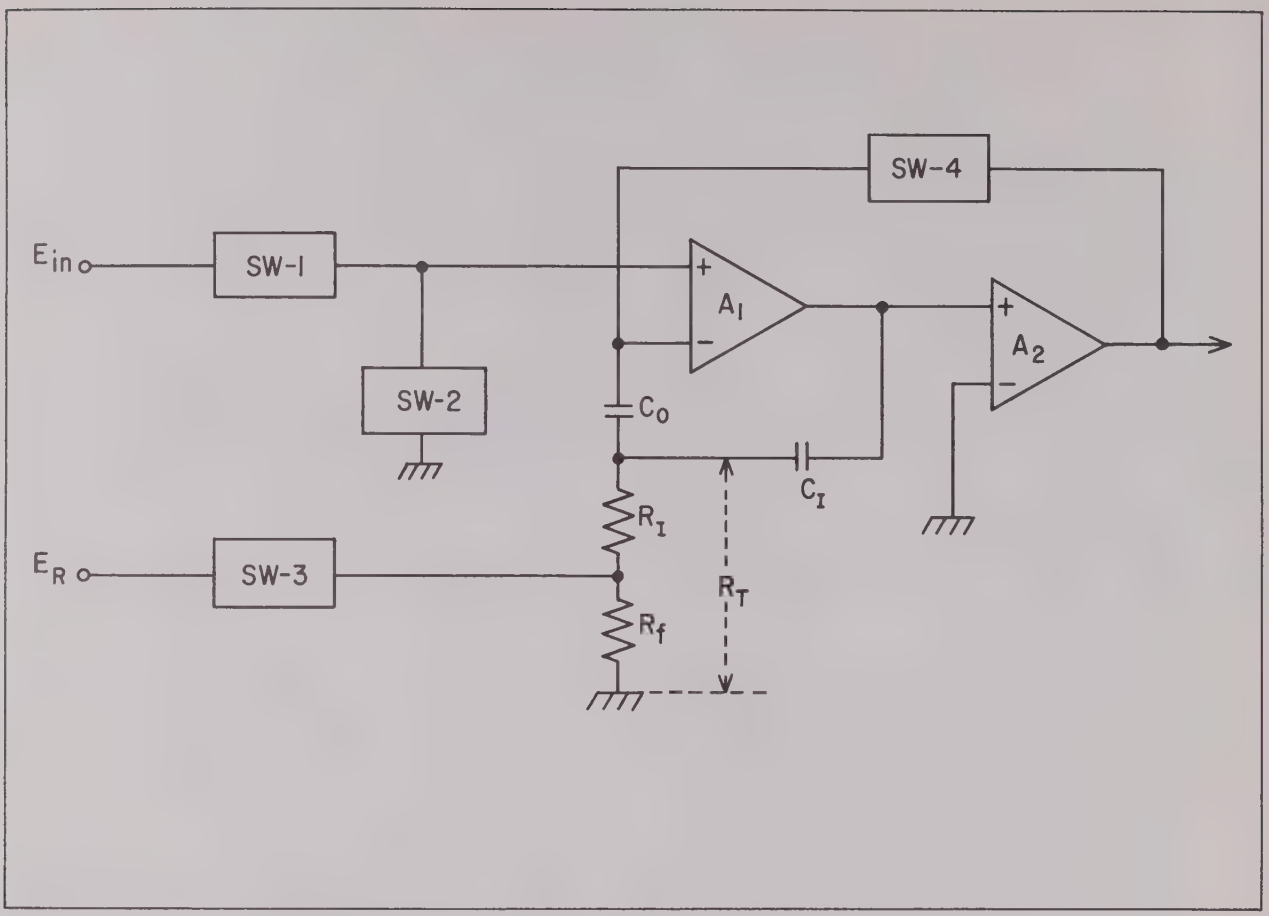


Figure 4. Simplified Block Diagram, Time Ratio Integration System

It is also important to note that the voltage across the resistor in figure 3 is equal to the source voltage minus the voltage across the capacitor.

At the time the switch is closed, $t = 0^+$, equation (1) yields zero voltage across the capacitor, as one would expect since the voltage across the capacitor cannot change instantaneously. Therefore, the full source voltage appears across terminals b and c or across R. Of significance is the fact that if R is infinite then $I = 0$ for all time then equation (1) is zero for all time, i.e., if R is infinitely large, then the capacitor drops no voltage and the voltage applied appears at the output or across terminals b and c.

These two theories comprise the basis for a unique, automatic zeroing, analog-to-digital converter used in this multimeter.

The simplified block diagram shown in figure 4 is the basic time ratio integration system. Amplifier A_1 is a high gain, high input impedance differential amplifier. Components C_I, R_I and R_f are the integration network. Capacitor C_o is the self-zeroing storage capacitor. Amplifier A_2 is a zero crossing detector.

The output of amplifier A_1 is always equal to the difference between the inverting input and non-inverting input times the gain as shown in equation (3).

$$E \text{ out } A_1 = (E_{in} - E_f) A \qquad (3)$$

Therefore, the output of A_1 is a large voltage if Ein and E_f are not equal. A_1 has a gain of approximately 10,000 so that a very small difference at the two inputs will drive the amplifier into saturation. This means that in order to balance the amplifier E_f must equal E_{in} for all practical purposes.

The conversion sequence begins with a condition in which SW-1 is open, removing E_{in} from the amplifier; SW-2 is closed, grounding the non-inverting input of the amplifier; SW-3 is open, removing the reference voltage; SW-4 is closed, setting the system into self-zero mode.

The output of amplifier A_2 is positive when its input is positive, negative when its input is negative and zero when its input is zero (neglecting offset). With SW-4 closed, the output of A_2 is connected

to the inverting input of A_1 and capacitor C_O. This comprises a closed loop from the output to the input of the over-all system. Feedback from A_2 to A_1 stabilizes the over-all system in a condition where necessary offset voltage is self-generated and stored in capacitor C_O. In self-zero mode, if offsets in the amplifiers tend to drive the output of A_2 positive or negative, a voltage will be developed at the inverting input of A1 of such magnitude as to compensate for the amplifiers offset. This voltage is stored in C_O and remains constant during the conversion sequence due to the high input impedance of A_1. After each conversion sequence SW-4 is again closed, up-dating the offset voltage for each cycle.

The system is now stabilized in a self-zero condition. The input sampling is accomplished by opening SW-2, SW-4 and closing SW-1, applying E_{in} to the non-inverting input of A_1. A_1 sees a step input from zero volts to E_{in}. At this time the inverting input is zero, so amplifier A_1 will tend to saturate positive. However, the step input to A_1 produces a step output and since the charge on C_I cannot change instantaneously this step appears at the top of R_I and at the inverting input through C_O. Therefore, instead of saturating, A_1 output steps from zero volts to a magnitude equal to E_{in} which balances the two inputs. (Note that C_O acts as a short circuit to voltages at R_I since A_1 input impedance is very high.) This condition would exist only momentarily since the inverting input is always equal to the voltage across R_I and R_f.

$$E_f = I(R_I + R_f)$$

$$R_I + R_f = R_T$$

$$E_f = IR_T \qquad (4)$$

In order to keep the input to A_1 balanced, a constant current as required in equation (4) must flow through R_T. This constant current is supplied by A_1 charging C_I at a constant rate. As discussed, a constant current through C_I necessitates a linear ramp voltage across C_I: therefore, the output of A_1 steps from zero to E_{in} and then ramps positive (if E_{in} is positive) linearly.

This closed loop feedback system is stable as long as $E_{in} = E_f$ or when the current through C_I is constant as required by equation (4).

The output of A_1 is the voltage across R_I, R_f and C_I.

$$V_{out} = \frac{I}{C_I}(t) + E_f$$

Since $E_{in} = E_f$ and from equation (4) $I = \frac{E_f}{R_T}$

$$V_{out} = \frac{\frac{E_{in}}{R_T}}{C_I}(t) + E_{in}$$

or

$$V_{out} = \frac{E_{in}}{R_T C_I}(t) + E_{in} \qquad (5)$$

Equation (5) is the expression for the voltage at the output of A_1 as a function of time, where the input voltage is E_{in}. This voltage steps, then increases linearly if E_{in} remains constant.

A similar condition exists if the non-inverting input of A_1 is set to zero (SW-1 open, SW-2 closed) and a positive voltage is applied through SW-3. This condition places a voltage E_R at the bottom of R_I. The non-inverting input of A_1 has stepped from E_{in} to zero so the output steps negative by E_{in} volts to again balance the two inputs. However, in order to maintain this balance condition there must exist a current through R_T to offset the reference voltage E_R. The magnitude of this current was expressed in equation (4).

Therefore, when E_{in} is removed and the reference is applied, the output of A_1 steps negative then ramps negative to produce a net sum of zero volts across R_T and therefore balanced inputs again at A_1.

The expression for the output of A_1 during this negative portion of the ramp is:

$$V_{out} = -\frac{E_R}{R_T C_I}(t) - E_{in} \qquad (6)$$

If the switches shown in figure 4 are sequenced in specific order, the output of A_1 may be made to ramp positive for a period of time while E_{in} is applied and negative for a period of time while E_R is applied. A ramp similar to that shown in figure 5 would be produced for the sequence shown in table 2.

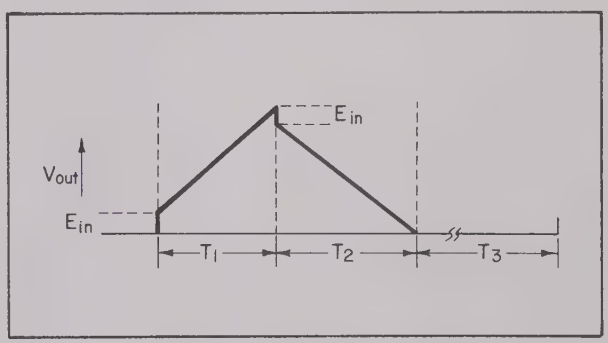


Figure 5. Integrator Output

Time	SW-1	SW-2	SW-3	SW-4
T_1	ON	OFF	OFF	OFF
T_2	OFF	ON	ON	OFF
T_3	OFF	ON	OFF	ON

Table 2. Switching Sequence

The equations for the up ramp and down ramp are (5) and (6). These equations are for all time but, in order to compare the unknown input voltage to a known reference voltage, the time it takes to charge C_I is compared to the time it takes to discharge C_I.

In figure 5 and table 2, if time T_1 is set to a specific value and time T_2 measured, then E_{in} is to T_1 as E_R is to T_2, or:

$$\frac{E_{in}}{E_R} = K \frac{T_1}{T_2} \qquad (7)$$

In this multimeter an oscillator is gated ON when E_{in} is applied to A_1 and allowed to run for 1000 cycles. At this point E_{in} is removed and E_R is applied and the oscillator continues to run during time T_2, for N_X cycles, until the output of A_1 again reaches zero volts (starting point). Therefore, from equation (7) E_{in} is related to E_R by the ratio of two series of pulses.

Since the increase in voltage out of A_1 during T_1 is equal to the decrease in voltage out during T_2 (returned to same voltage level) equations (5) and (6) must be equal for time T_1 and T_2, i.e., the sum of equation (5) and (6) over the two time periods must equal zero.

$$T_1 = \frac{1000}{f} \qquad (8)$$

$$T_2 = \frac{N_X}{f} \qquad (9)$$

f = oscillator frequency

N_X = number cycles during time T_2

Substituting equation (8) and (9) into equations (5) and (6) and summing the two equal to zero.

$$\frac{E_{in}}{R_T C_I}\left(\frac{1000}{f}\right) + E_{in} = \frac{E_R}{R_T C_I}\left(\frac{N_X}{f}\right) + E_{in}$$

Simplifying:

$$\frac{E_{in}}{R_T C_I f}\ 1000 = \frac{E_R}{R_T C_I f}\left(N_X\right)$$

and:

$$N_X = \frac{E_{in}}{E_R}\left(1000\right) \qquad (10)$$

Therefore, the number of pulses during the application of the reference voltage is proportional to the input voltage and the reference voltage.

If N_X is displayed on some type of readout device and the constant, $\frac{1000}{E_R}$, is adjusted to make N_X directly proportional to E_{in}, the system would then be a single-range voltmeter.

The accuracy of the analog-to-digital conversion is dependent only on the reference voltage. The frequency of the oscillator, amplifier gain, integrating capacitor and resistor do not appear in equation (10) and do not affect the accuracy of the system as long as they are within reason.

Most significant is the fact that the over-all system is automatically zeroed prior to each cycle and is able to maintain exceptional stability during the cycle. Zero drift and the subsequent offset in readings have been eliminated.

SECTION VI
CIRCUIT DESCRIPTION

The circuitry discussed in Theory of Operation plus the circuitry necessary to count and display N_X and thereby indicate the magnitude of the units being measured is shown schematically in figure 17 and block diagram form in figure 6.

The basic system has a full scale input sensitivity of 90.909 mV and is linear up to 100% overrange. All ranges are divided down to this level as a particular full scale input range is selected.

Range Switch S2

The range switch sets the full scale input value on all functions. This switch selects the appropriate dividers or range resistors to produce 90.909 mV input to the integrator for a full scale reading.

Function Switch S1

The function switch selects the particular unit to be measured. These units are dc volts and current, ac volts and current, and ohms. The function switch has provisions for checking battery voltage and de-energizing the unit.

Filter

The integrator input filter consists of an RC network which, when combined with the integrator, provides high ac noise rejection. The rejection is specified in Section II.

SW-1 and SW-2

SW-1 and SW-2 are the input switches consisting of junction FET's Q2 and Q4 and are controlled by bipolar inverters. When SW-1 is on and SW-2 is off, the input voltage is applied to the integrator. When SW-1 is off and SW-2 is on, the integrator is returned to ground.

SW-3a and SW-3b

The SW-3a and SW-3b are reference switches and are controlled by a flip-flop which is set according to input polarity. These switches are junction FETs Q18 and Q19.

Flip-flop

This is a controlled R-S flip-flop. The inputs are driven by Apply-1 and the polarity sensing circuitry. The flip-flop also has provisions for inhibit and output gating.

Reference Voltages

The negative reference voltage is generated by a temperature compensated zener, CR13, and constant current supply. This combination produces a reference voltage that is highly stable with very little or no effects from temperature or supply voltage. The plus reference is derived from this stable negative reference through use of a unity-gain inverting amplifier consisting of Q43 and Q44. Q43 is a matched differential pair to minimize temperature effects and the amplifier is compensated for variation in supply voltage.

The reference zener is only switched on when it is applied to the integrator to minimize power consumption.

Amplifier A_1

A_1 is the integrating amplifier described in Theory of Operation, Section V. This amplifier consists of a FET input differential stage, Q6 and Q11, which provides the necessary high input impedance, a bipolar differential stage, Q7 and Q10, and a bipolar inverting amplifier, Q9. The amplifier gain is high (approximately 10,000) to reduce the total conversion error to less than 0.1%. The input FET stage is operated at approximately 0.5mA per section supplied from a constant current source, Q8, with common mode feedback.

Amplifier A_2

A_2 is a high gain differential amplifier that serves as a zero crossing detector or comparator. Its function is to indicate when the integrator output ramp crosses zero volts or the voltage from which it started. The amplifier consists of two bipolar diffential stages, Q15 and Q17, Q14 and Q16. The high gain of A_2 makes it sensitive to ramps produced by inputs down to 50 u V; consequently, the system is able to make accurate measurements with 100 u V resolution. The output of A_2 ultimately controls the oscillator from which the display (N_X) is obtained.

Inverter 1 and Inverter 2

Inverter 1 and Inverter 2 sense the output of A_2. This output is positive for positive inputs and negative for negative inputs. The oscillator (in MOS-IC) is controlled by the YN input. The oscillator is ON when this input is low and OFF when this input is high. Therefore, Inverters 1 and 2, Q22 and Q26, sense the polarity and control the oscillator through YN. Inverter 1 senses positive polarity and is gated such that it may not control YN when the polarity is negative. Inverter 2 senses negative polarity and sets the flip-flop for negative polarity. Inverter 2 controls the oscillator through YN via SW-5.

SW-5

SW-5 consists of bipolar transistors Q28 and Q29, SW-5 is discussed under Megohms Operation, Section VII. It allows Inverter 2 to control the oscillator only when Apply-2 output is low.

Reset Generator

The reset pulse is generated by a multivibrator with a high on-off ratio. The reset pulse is approximately 50 u s wide and occurs every 0.5 seconds. Transistors Q38 and Q39 form the multivibrator; R85 and C18 determine the rate; R84 and C19 determine the pulse width.

SW-7

SW-7 controls the Polarity Sign. Transistor Q36 monitors the state of the flip-flop. When the flip-flop is set for positive polarity, (apply a positive reference) Test Point J goes to 0 volts turning Q36 on. Q36, in turn, turns Q34 on, lighting the "+" sign, and applies -13.5V to the base of Q33 extinquishing the "-" sign. When Q36 is off, "-" polarity, Q34 is off and Q33 has +11.5V applied to its base lighting the "-" sign.

Regulators

Transistors Q50, 51, 52, 53 and associated circuitry form a -13.5 regulator. The positive regulator, controlled by Q48 and Q49, is referenced to the negative regulator and adjusted for + 11.5V.

Battery Charging Circuit

The charging circuit is designed to recharge the + 14.4 volt, -14.4 volt and 1.25 volt nickel-cadmium batteries. The circuit consists of a transformer, half wave rectifier and filter with current limiting resistors.

Charging time for completely discharged batteries is approximately 16 hours. The multimeter may be operated during recharge, in which case the charging circuit is charging the batteries at 30% of capacity.

MOS-IC

The MOS-Integrated Circuit Z2 is designed specifically for this equipment. It contains an oscillator, three-stage counter, count storage latches, seven-segment decoder driver, and additional gating circuits to control the sequence of events in the multimeter. The output waveforms are shown in figures 10 and 11. The sequence is discussed in the Functional Operation, Section VII.

The MOS-IC is a 40-pin dual in-line package. It is compact and consumes very little power, enabling the multimeter to operate for long periods of time before battery recharge is necessary.

AC DC Converter

The ac/dc converter consists of a triple cascode FET follower coupled with an operational amplifier and hot carrier diode rectifiers. Transistor Q42 serves as a current source with negative dc feedback to stabilize the dc operating point of the operational amplifier Z1. The input FET, Q40, is bootstrapped via Q41 and C30, which feeds back a signal of the same phase and amplitude as the input signal. This unique configuration provides maximum input resistance and minimizes input capacitance, thus allowing use of a pure capacitive input divider. Frequency response of the ac system is specified from 22 Hz to 100kHz and has a constant input impedance of $\approx$ 75 pF.

Hot carrier diodes CR5 and CR6 form a full wave rectification circuit. The output is taken from one side of this circuit and is proportional to the average of the input signal. This signal is filtered and calibrated such that the dc output is proportional to the rms value of the input signal (for pure sine-waves).

Resistors R98, R100 and R101 determine the closed loop gain of the converter. The two half wave rectified signals are reconstructed at the junction of these three resistors and fed to the input of the amplifier. This closed loop contains the amplifier, ac coupling capacitor, and rectifier diodes, thus minimizing errors due to capacitor reactance or diode forward voltage drop and recovery time.

Components C27, R88, R89 and R94 provide input overload protection of 250V on the 100 mV range and 1000V on all other ranges.

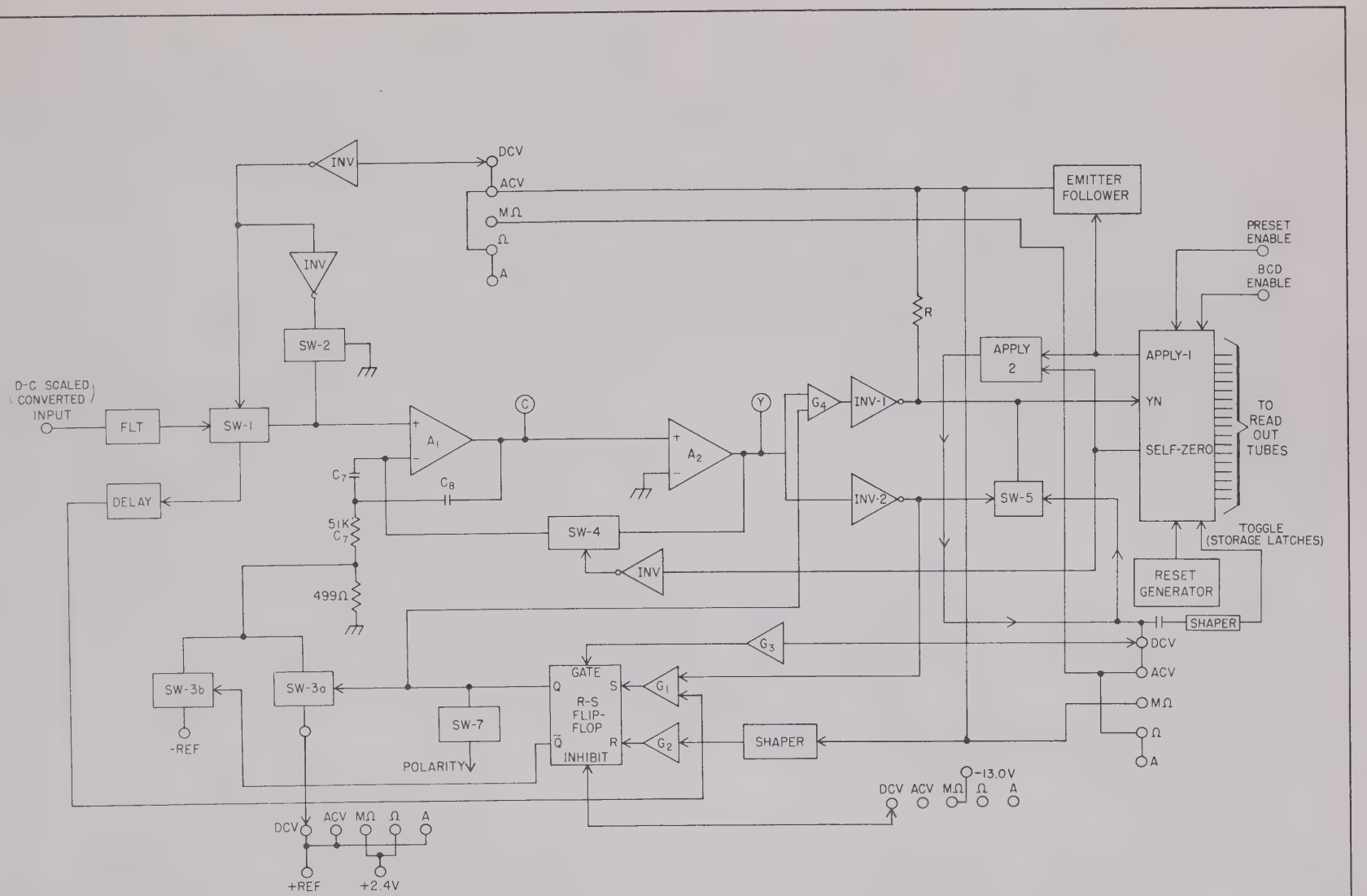


Figure 6. Complete Block Diagram

SECTION VII
FUNCTIONAL OPERATION

The multimeter is basically a dc voltmeter with a full scale sensitivity of 100 mV at the input terminals. Series and shunt resistors are switched in or out of the circuit to accomplish range changes and an ac/dc converter is switched in to permit ac measurements. Otherwise, the basic operation of the instrument is identical on all ranges and functions except megohms. The operation of the megohms measuring circuitry is described later in this section.

Table 3 lists the state of various switching functions during the three segments of the measurement sequence. These three segments are self-zero, count to 1000 or ramp by E_{in}, and count

$$N_x = \frac{E_{in}}{E_R} (1000)$$ or ramp by ER.

POSITIVE DC VOLTS

Referring to the simplified block diagram, figure 4 complete block diagram, figure 6, integrator output waveform figure 5, and the sequential event chart, table 3, consider the system to be in the self-zero mode. At this time, SW-4 is closed, connecting the output of A_2 to the inverting input of A_1. This forms a closed loop self-zeroing system in which amplifier offsets are automatically adjusted by placing the necessary offset voltage on C7.

Apply -1 and Apply -2 are off at a level of + 10V setting:

SW-1 off	-removing E_{in}
SW-2 on	-grounding the integrator input
SW-3a, b off	-removing E_R
SW-4 on	-self-zeroing

1. The next event is the generation of the reset pulse. The reset is self-generating and does not depend on other events. When the MOS-IC receives a reset pulse the following occurs:

a. MOS counters reset to 000.

b. Apply -1 turns ON (-13V).

(1) YN turns on (0V)

(2) SW-1 on; SW-2, SW-4 off

E_{in} is positive and is applied to the input of A_1 via SW-1. The output of A_1 begins ramping positive with a slope determined by E_{in}. The oscillator is running, being turned on by YN, and the MOS counters are counting the oscillator cycles. YN is held on by Apply -1 such that with zero volts in and consequently no ramp, the integrator remains on for 1000 counts.

2. The counter reaches a count of 1000 at which time an internal overspill pulse generates the following events:

a. Apply -1 turns off (+11V).

(1) SW-1 off.

(2) SW-2 on.

(3) Flip-flop automatically set to positive polarity via gate G2.

(4) Counters preset to 000.

b. Apply -2 turns on (-13V).

(1) Flip-flop output gated to SW-3a and SW-3b.

(a) SW-3a on.

(b) Gate G4 and Inverter -1 on.

$+E_R$ is applied to the integrator. The output steps negative by the magnitude of E_{in} and then ramps negative with a slope determined by $+E_R$. YN is held on by Inverter -2, allowing the oscillator to run.

3. When the Integrator output ramp crosses the zero reference, the output of A_2 turns off (0V)

OPERATING MODE	INTE-GRATOR INPUT	APPLY -1	APPLY -2	SELF-ZERO	SW-1	SW-2	FLIP-FLOP		INTEGRATOR		COM-PARATOR OUTPUT	SW-5	YN	NOTES	
							SW-3a	SW-3b	SLOPE	POLARITY					
SELF-ZERO	GND.	OFF	OFF	ON	OFF	ON	OFF	OFF	0	0	0±.4V	OFF	OFF	POSITIVE INPUT	
RESET															
COUNT TO 1000	$-E_{in}$	ON	OFF	OFF	ON	OFF	OFF	OFF	+	+	+	OFF	ON		RAMP + $B_y + E_{in}$
MOS-SWITCH															
COUNT TO N_x	GND.	OFF	ON	OFF	OFF	ON	ON	OFF	-	+	+	ON	ON		RAMP - $B_y - E_r$
ZERO-CROSS															
	SELF ZERO AND COUNT TRANSFERRED TO DISPLAY														
	SELF-ZERO													NEGATIVE INPUT	
RESET															
COUNT TO 1000	$-E_{in}$	ON	OFF	OFF	ON	OFF	OFF	OFF	-	-	-	OFF	ON		RAMP - $B_y - E_{in}$
MOS-SWITCH															
COUNT TO N_x	GND.	OFF	ON	OFF	OFF	ON	OFF	ON	+	-	-	ON	ON		RAMP + $B_y - E_r$
ZERO-CROSS															
	SELF-ZERO AND COUNT TRANSFERRED TO DISPLAY														
	SELF-ZERO												OFF (-11V)	MEGOHMS OPERATION	
RESET															
COUNT TO 1000	GND.	ON	OFF	OFF	OFF	ON	ON	OFF	-	-	-	OFF	ON		RAMP - $B_y + E_r = \frac{R_f}{R_f + R_{cal}}(2.4V)$
MOS-SWITCH															
COUNT TO N_x	$+E_{in}$	OFF	ON	OFF	ON	OFF	OFF	OFF	+	-	-	ON	ON		RAMP + $B_y + E_{in} = \frac{R_b}{R_b + R_x}(2.4V)$
ZERO-CROSS															
	SELF-ZERO AND COUNT TRANSFERRED TO DISPLAY														

NOTE: AC Volts, AC + DC Current and Ohms Operations Identical to Positive Input.

Table 3. Sequential Event Chart

and Inverter -1 turns YN off (+ 11V). The following events take place when YN turns off:

a. Oscillator stops (inhibited by YN).

b. Apply -2 turns off (+ 11V).

(1) Flip-flop outputs off.

(a) SW-3a and SW-3b off.

c. Self-zero turns on.

(1) SW-4 on.

d. Count (N_X) transferred to display.

The counters now display the number of cycles that occurred during the ramp down or Nx as defined in equation (10), Section V. The system is returned to the self-zero mode and remains in that state until the next reset pulse occurs.

The count to 1000, time (T_1), is approximately 100 ms. The time for Nx pulses (T_2) is 100 ms for full scale and 200 ms for twice full scale.

The display will remain unchanged if the count (N_X) is the same as the previous count. Latches in the MOS-IC store the displayed reading until a new reading has been taken.

NEGATIVE DC VOLTS

The operation for negative dc volts is very similar to positive dc volts. The three segments of the sequence remain identical. However, YN is controlled by Inverter -2 rather than Inverter -1; the flip-flop is set to apply a negative reference and indicate negative polarity on the display.

When E_{in} is applied to the amplifier via SW-1, the output steps negative by a magnitude of E_{in} and then ramps negative. At the end of T_1, 1000 counts, Apply -1 turns off and Apply-2 turns on. Apply-1 turns SW-1 off, SW-2 on and sets the flip-flop to positive polarity. The delay network connected to SW-1 opens gate G1 for several microseconds at the end of T_1, thus allowing Inverter-2 to switch the flip-flop to negative polarity. Since the ramp is negative, the output of A_2 will be negative and Inverter -2 will be on, setting the flip-flop to apply a negative reference. The negative reference then causes the output of A_1 to ramp positive toward zero volts.

At zero crossing, end of T_2, YN is turned off via A_2, Inverter-2 and SW-5, thus stopping the oscillator and the number N_X is displayed.

OHMS OPERATION

In order to measure resistance, the multimeter applies a constant current to the resistor to be measured (R_x) and then measures the dc voltage dropped across the resistor.

As shown in the Simplified Switching Diagram, figure 7, 2.4 volts is applied to the HI Input through resistor R_b. Resistor R_b is 100 times the full scale resistance value to reduce non-linearity in the current generator. This, coupled with the reference calibration, reduces the ohmmeter error to less than 0.3% of full scale.

The block diagram for ohms operation is shown in figure 8. System operation and switching are the same as described for +dc volts.

When an unknown resistor is placed across the Input, a voltage is developed at the input of the system as determined by R_b, R_x, and the + 2.4V supply. This voltage will be:

$$E_{in} = \frac{R_x}{R_x + R_b} \quad (2.4) \qquad (11)$$

This voltage, when applied to the integrator through SW-1, will produce a positive ramp as described in + dc volts operation.

From Theory of Operation, the digital display obtained from this input will be:

$$N_x = \frac{E_{in}}{E_R} \quad (1000) \qquad (10)$$

However, E_{in} is now expressed by equation (11) and E_R is determined by the voltage division of R_{cal} and R_f.

Therefore:

$$E_R = \frac{R_f}{R_f + R_c} \quad (2.4) \qquad (12)$$

Substituting equation (11) and (12) into equation (10):

$$N_x = \frac{\frac{R_x}{R_x + R_b}\ (2.4)}{\frac{R_f}{R_f + R_c}\ (2.4)}\ (1000)$$

Simplifying:

$$N_x = \left(\frac{R_x}{R_x + R_b}\right)\left(\frac{R_f + R_c}{R_f}\right)\ (1000) \qquad (13)$$

The term $\frac{R_f + R_c}{R_f}$ is a constant and is adjusted in calibration to be approximately equal to 100. Therefore:

$$N_x = \frac{R_x}{R_x + R_b}\ (100,000) \qquad (14)$$

N_x is proportional to the resistive divider formed by R_x and R_b. If R_b is large in respect to R_x then N_x is directly proportional to R_x. At full scale

$$\frac{R_x}{R_x + R_b} = \frac{1}{1+100} = \frac{1}{101}.$$

It should be noted that the ohmmeter supply voltage (+2.4V) has no effect on the ohmmeter accuracy since it is used for both input divide supply and reference supply.

MEGOHMS OPERATION

The multimeter has been designed to make resistance measurements up to 199.9 megohms. This is accomplished by measuring $\frac{1}{R}$ and displaying the reciprocal of that measurement.

The block diagram for megohms operation is shown in figure 9.

Significant differences between the Megohms and Ohms circuitry are:

1. The input resistive divide consisting of R_x and R_b is inverted.

2. The reference voltage is applied to the integrator during T_1. The R-S flip-flop is set to apply a positive reference by locking it in a positive state.

As shown in the simplified switching diagram, figure 7, + 2.4 volts is applied to the LO input terminal. Rb is connected between the HI input terminal and ground.

When an unknown resistor is placed across the Hi and LO terminals, a voltage is developed at the input or at SW-1. This voltage will be:

$$E_{in} = \frac{R_b}{R_x + R_b}\ (2.4V) \qquad (15)$$

This voltage is not applied to the integrator until Apply-2 occurs (Time T_2). When the reset occurs, Apply-1, via gate G3 and the flip-flop, applies a positive reference voltage to the integrator. This voltage produces a negative going ramp for the time period T_1 or 1000 counts.

At the end of 1000 counts Apply-1 turns off and Apply-2 turns on. This removes the reference voltage and applies the input voltage, producing a ramp with positive slope so the output of A_1 begins ramping back toward zero volts.

When the ramp crosses zero volts, A_2 switches to zero and Inverter-2, via SW-5, switches YN off, stopping the oscillator. SW-5 is then turned off as Apply-2 turns off and the system switches to self-zero mode and displays the number of cycles that occurred during time T_2.

The output voltage change of A_1 during T_1 (ramp down by + E_R) will be:

$$V_{out} = \frac{E_R}{R_T C_I}\left(\frac{1000}{f}\right) \qquad (16)$$

Where:

$$E_R = \frac{R_f}{R_f + R_c}\ (2.4V) \qquad (17)$$

Therefore:

$$V_{out} = \frac{\frac{R_f}{R_f + R_c}}{R_T C_I}\left(\frac{1000}{f}\right)\ (2.4V) \qquad (18)$$

The output voltage change of A_1 during T_2 (ramp up by + E_{in}) will be:

$$V_{out} = + \frac{E_{in}}{R_T C_I}\left(\frac{N_x}{f}\right) + E_{in} \qquad (19)$$

where E_{in} is expressed in equation (15).

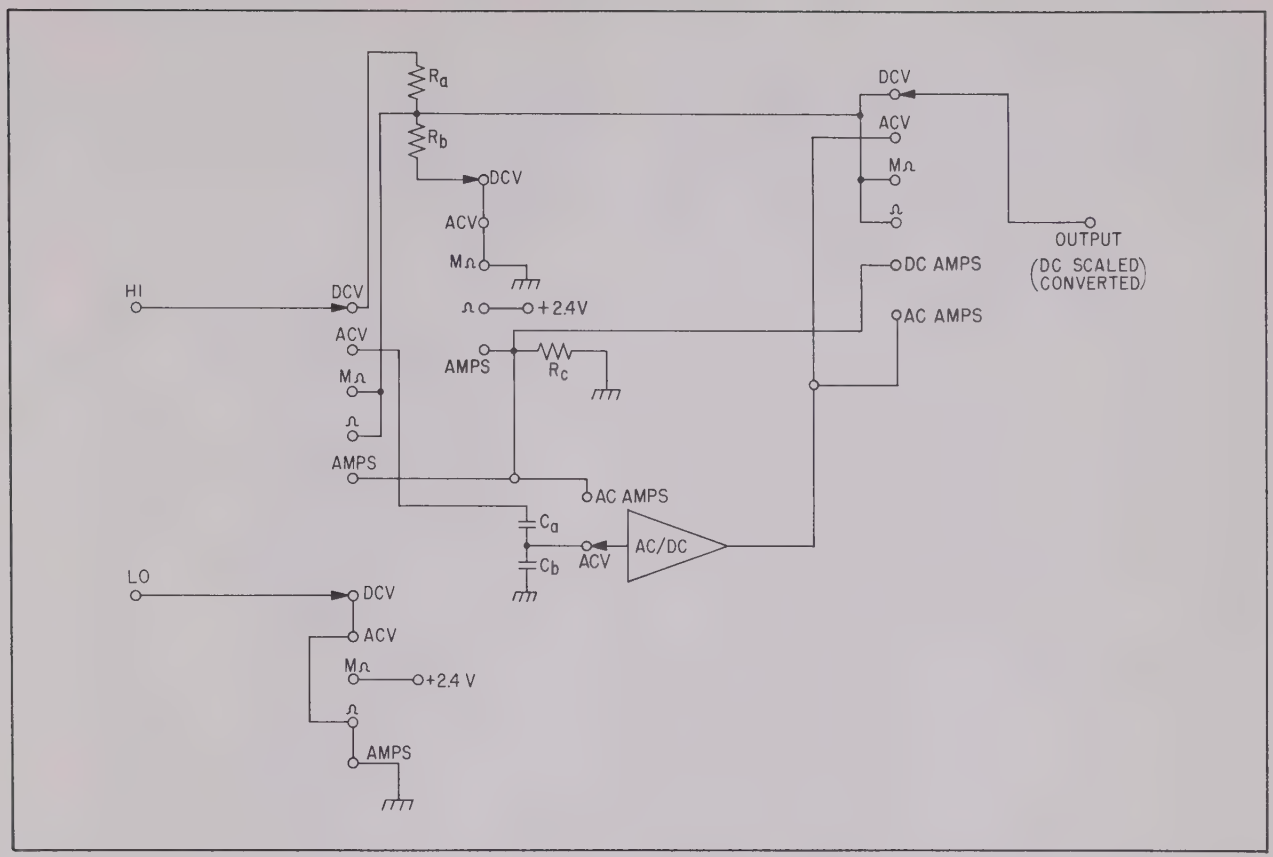


Figure 7. Simplified Switching Diagram

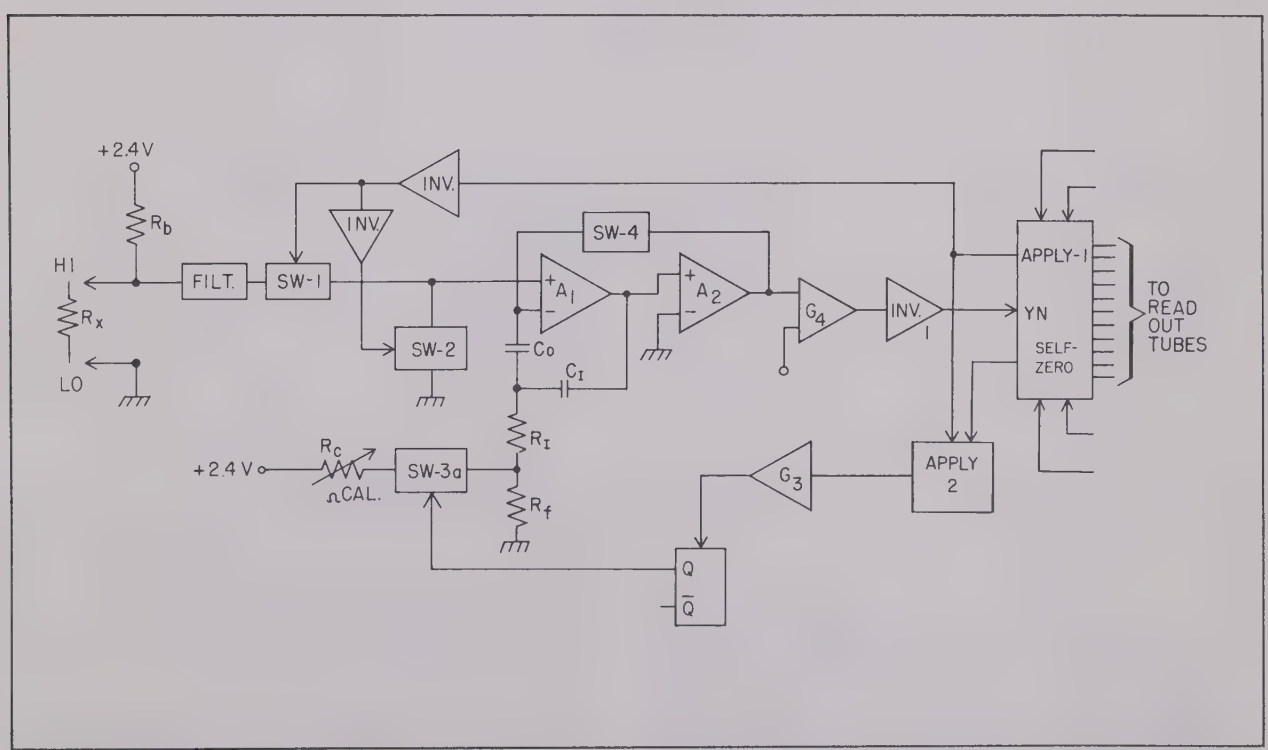


Figure 8. Ohms Block Diagram

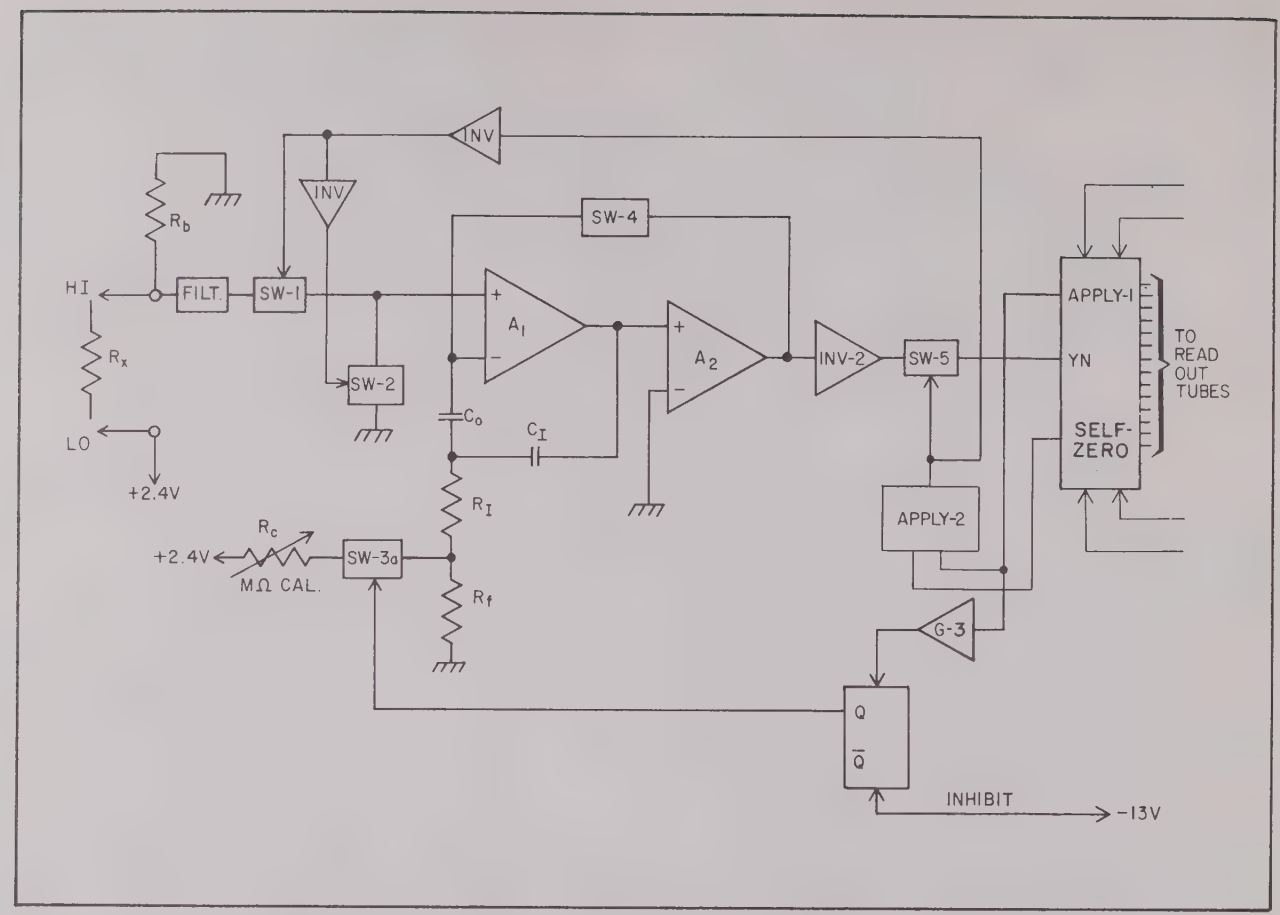


Figure 9. Megohms Block Diagram

Equating equation (18) and (19):

$$\left(\frac{R_f}{R_f R_C}\right)\left(\frac{1}{R_T C_I f}\right)\left(1000\right)\left(2.4\right) =$$

$$\left(\frac{R_b}{R_x+R_b}\right)\left(\frac{1}{R_T C_I f}\right)\left(N_x\right)\left(2.4\right) + \left(\frac{R_b}{R_x+R_b}\right)\left(2.4\right)$$

Therefore:

$$N_x = \left(\frac{R_f}{R_f R_c}\right)\left(\frac{R_x+R_b}{R_b}\right) 1000 - R_T C_I f \qquad (20)$$

The term $\frac{R_f}{R_f+R_c}$ is a constant and is adjusted in calibration to be 1/100.

Equation (20) is of the same form as the equation for the ohms reading with the exception of the term $-R_T C_I f$. For the megohms ranges R_T is adjusted such that this term is equal to 10 and exactly compensates for the non-linearity in the input resistive divide. Therefore, the megohms ranges are linear and may be used up to twice full scale.

Significantly, if R_X is zero ohms, i.e., HI and LO connected together, then $\frac{R_x + R_b}{R_b}$ is equal to one and N_X is equal to zero. Functionally, E_R is applied to the integrator for 1000 counts, E_{in} is then switched to the integrator (E_{in} is now equal to the ohmmeter supply voltage, +2.4V); in order to balance the inputs to the integrator the output steps positive by the amount of E_{in}, or 2.4V. From equation (18), if $R_T C_I f$ is equal to 10 then V_{out} at T_1 is equal to -2.4V and the application of E_{in} drives the integrator output back to zero, shutting off A_2 and ultimately YN to display a reading of 000.

AC VOLTS AND CURRENT OPERATION

In ac volts and current the ac/dc converter is used to convert the input signal to a dc voltage. This dc voltage is then displayed as any other dc voltage, except that the polarity indicator is turned off. The converter output is positive and is calibrated such that the + dc reference can be used.

The HI input terminal is connected to a calibrated capacitive divider which is switched for full scale ranges of 100 mV to 1 kV.

AC current is measured by monitoring the voltage across the shunt resistors and converting this ac signal to a dc voltage via the 100 mV AC VOLTS range.

DC CURRENT OPERATION

In dc current measurements, shunt resistors are switched across the input terminals. The voltage dropped across these shunts is monitored and displayed identical to the dc voltage reading. Polarity is automatically indicated as discussed under SW-7.

Since the basic analog conversion is designed to display 100.0 mV for 90.909 mV input, a fixed resistor, R122, is switched across R49 in all positions except DC AMPS. This changes the system from 90.909 mV to 100.0 mV sensitivity. This increases the resistor R_f in dc current mode to produce an exact 100.0 mV reference supply.

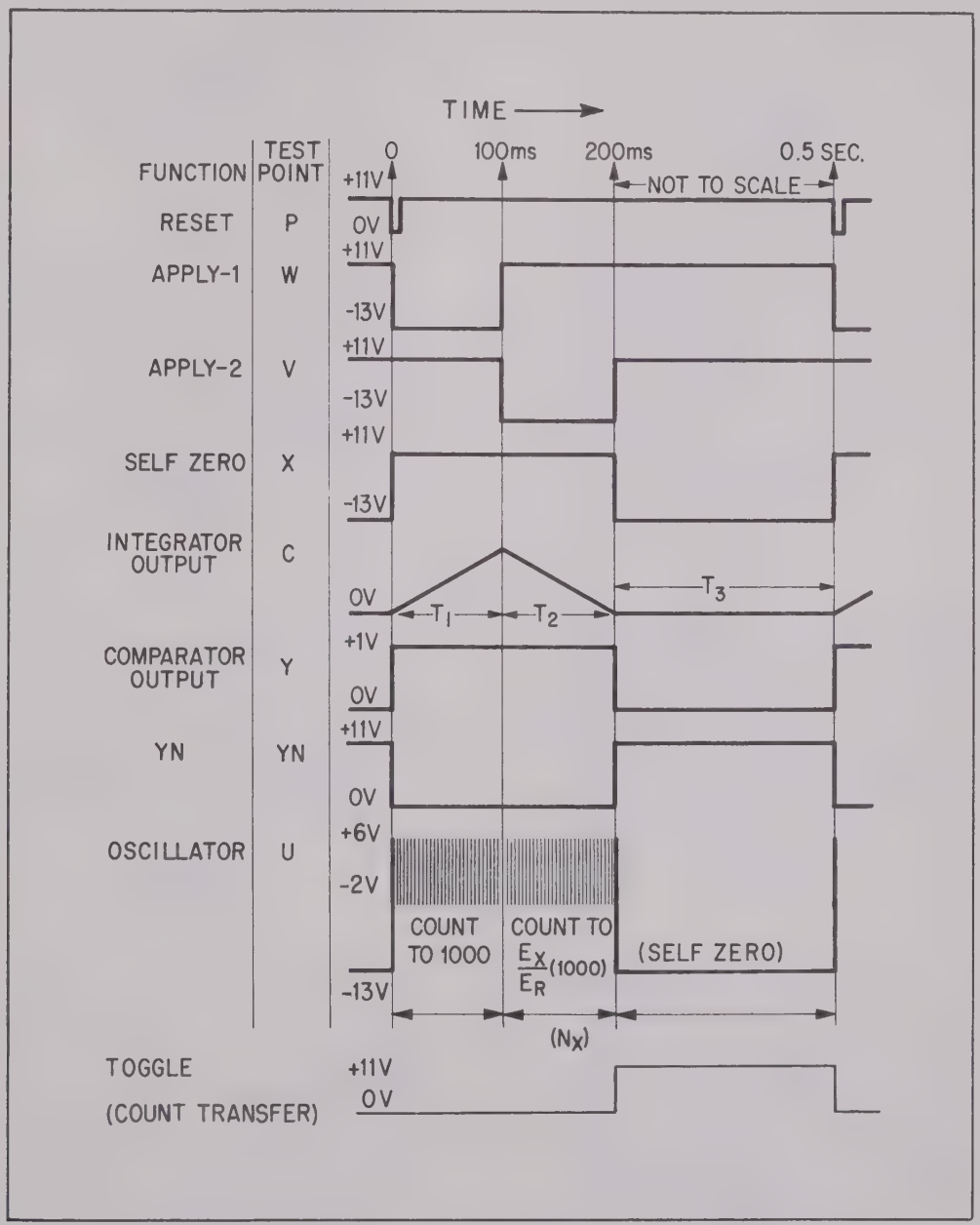
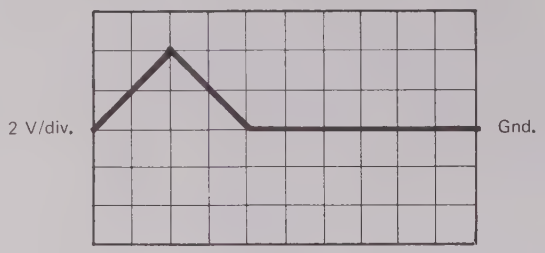


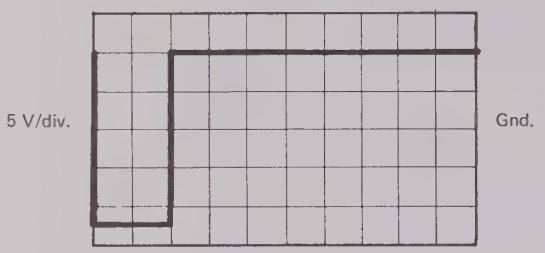
Figure 10. Waveforms - dc to Frequency System

(a)



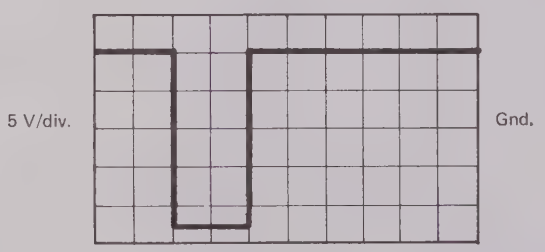
50 msec./div.
Integrator output (+fullscale)
Point – C

(b)



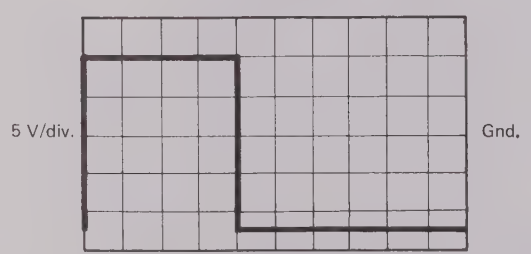
50 msec./div.
Apply – 1
Point – W

(c)



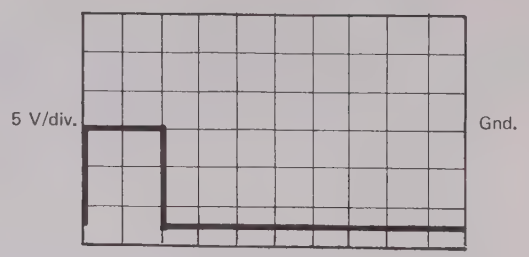
50 msec./div.
Apply – 2
Point – V

(d)



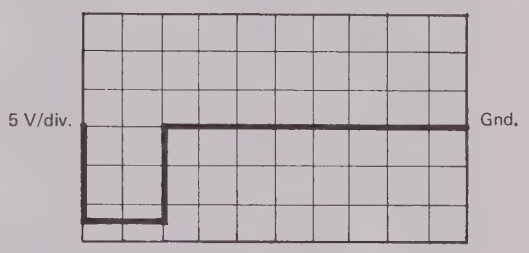
50 msec./div.
Self-Zero
Point – X

(e)



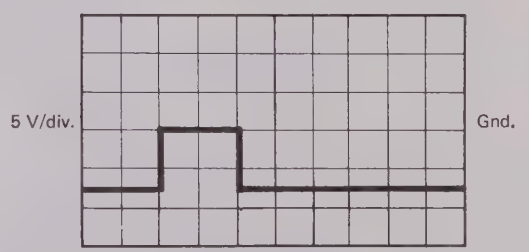
50 msec./div.
Series FET Gate (SW-1)
Point – AA

(f)



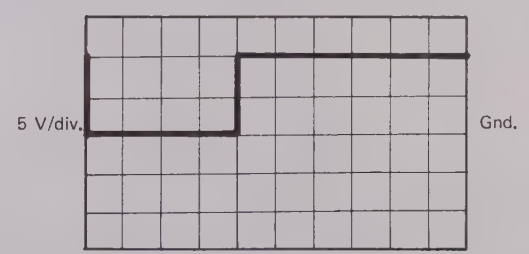
50 msec./div.
Shunt FET Gate (SW-2)
Point – A

(g)



50 msec./div.
Flip-Flop Gating
Point – I

(h)

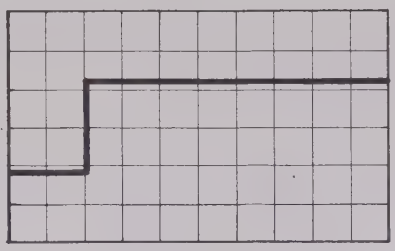


50 msec./div.
YN Signal
Point – YN

NOTE: Waveforms taken with 10:1 scope probe. Ext. trigger to Point–W – Negative Trig. Slope – +100 MV input on 100 MV D.C. range unless otherwise specified.

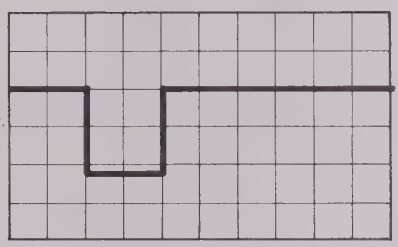
Figure 11. System Waveforms (Sheet 1 of 3)

(i)



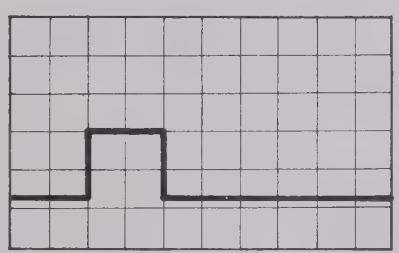
50 msec./div.
Base Q-1 (SW-1 Series FET Drive Switch)
Point – B

(j)



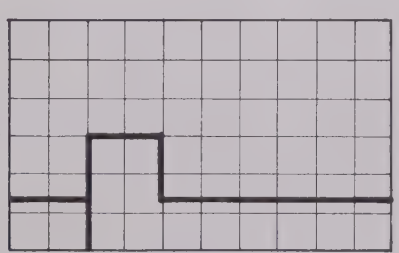
50 msec./div.
Base Q-44 (Flip-Flop Gating – Drive Signal)
Point – BB

(k)



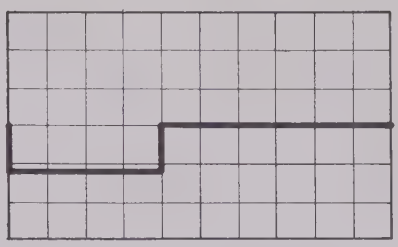
50 msec./div.
100 MV D.C. Range +100 MV Input
Point – J

(l)



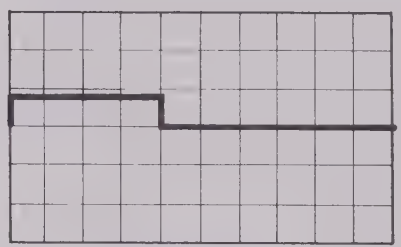
50 msec./div.
100 MV D.C. Range -100 MV Input
Point – JJ

(m)



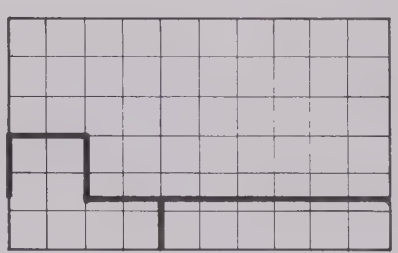
50 msec./div.
100 MV D.C. Range -100 MV Input
Point – Y

(n)



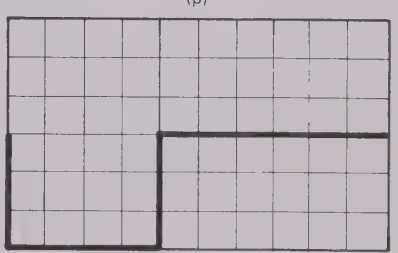
50 msec/div.
100 MV D.C. Range +100 MV Input
Point – Y

(o)



50 msec./div.
1 MΩ Range 1 MΩ Input
Point – J

(p)

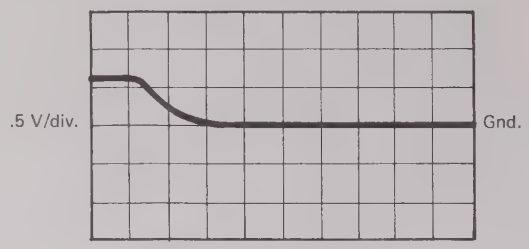


50 msec./div.
Self-Zero FET Gate
Point – D

NOTE: Waveforms taken with 10:1 scope probe. Ext. trigger to Point–W – Negative Trig. Slope – +100 MV input on 100MV D.C. range unless otherwise specified.

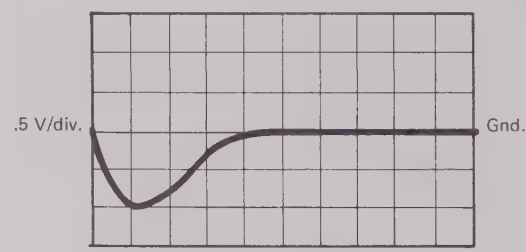
Figure 11. System Waveforms (Sheet 2 of 3)

(q)



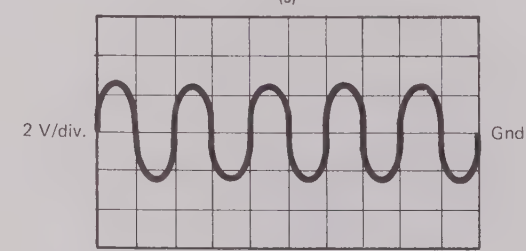
10 usec./div.
Flip-Flop (Positive Polarity Set Signal)
Point – HH
Sync T.P.W, + Slope

(r)



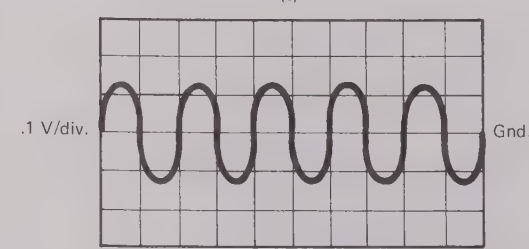
10 usec./div.
Flip-Flop (-Gating Signal)
Point – H
Sync T.P;W, † Slope

(s)



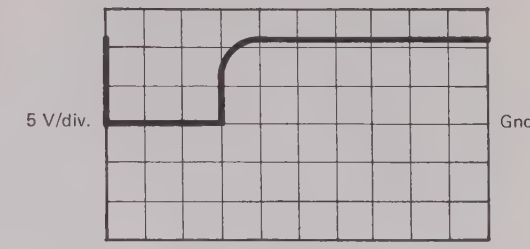
.5 msec./div.
AC/DC Converter (Z-100 Output)
Point – O
Sync Internal

(t)



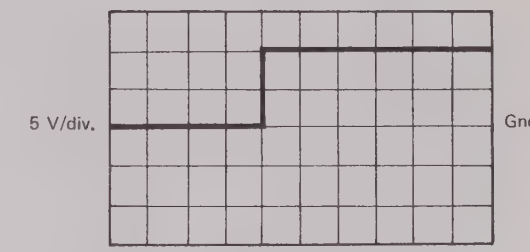
.5 msec./div.
AC/DC Converter (Feedback)
Point – SS

(u)



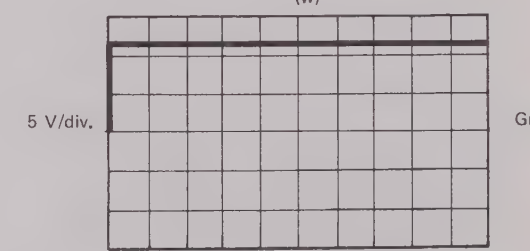
20 usec./div.
Reset Pulse
Point – P

(v)



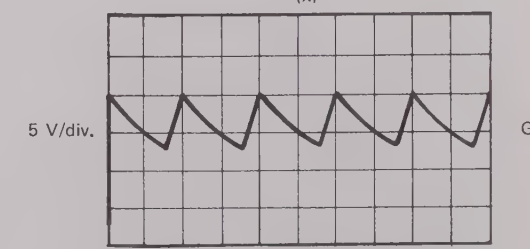
50 msec./div.
Latch Toggle
T.P. – R

(w)



.5 msec./div.
Latch Toggle
T.P. – R
Sync. – + INT.

(x)



50 usec./div.
Oscillator
T. P. – U

NOTE: Waveforms taken with 10:1 scope probe. Ext. trigger to Point–W – Negative Trig. Slope – +100 MV input on 100 MV D.C. range unless otherwise specified.

Figure 11. System Waveforms (Sheet 3 of 3)

SECTION VIII
TROUBLESHOOTING

It is recommended that sections of this manual dealing with theory of operation and functional operation be thoroughly understood before attempting to initiate corrective action.

In every instance a complete evaluation of the multimeter's performance should be made from the front panel and, if possible, the probable malfunctioning circuit isolated prior to disassembly of the unit.

RECOMMENDED EQUIPMENT

1. DC Standard and Differential Voltmeter (Hewlett-Packard Model 740B).
2. Hickok Model 5002 Oscilloscope with two 10:1 Probes (Hickok Style 100-155).
3. DC Microvoltmeter and AC Voltmeter (Hickok Models DP110 and DP130 with Model 3202 Digital Main Frame).
4. Sine Wave Oscillator (Krohn-Hite Model 4200).

TROUBLESHOOTING

The circuitry is divided into the following sections:

1. MOS-IC outputs and display
2. Integrator
3. Comparator
4. Input and Self-Zero Switching
5. Reference Switching
6. Output circuitry and oscillator control (Yn)
7. Function and Range switching
8. Voltage Regulators
9. Reset Circuitry and Latch Toggle
10. Reference Supply
11. Power Supply
12. AC/DC Converter and Associated Circuitry

1. MOS-IC Outputs and Display

a. The Seven Segment tubes are driven directly from the MOS-IC. The filaments of each tube is elevated to the -13.0 volt supply and the MOS-IC internal drivers are connected to the + 11.5 volt supply (Subs +) such that when the segment driver is "on" there is 24.5 volts across the tube. If all other sections are operating properly the drivers may be checked by observing the segments of each tube.

b. If there is no count displayed, refer to paragraph 9 of this section for reset pulse and latch toggle problems. It should be noted at this point that the MOS-IC contains latches such that the information obtained during each read cycle is stored until updated by a high signal (> + 8.0 V) at the latch toggle input (Pin 18). If Pin 18 is held high, the output of the latches follows the input and each count pulse is transferred directly to the display tubes.

c. The count pulses are generated by an oscillator on the MOS-IC chip. The oscillator is controlled by the Yn signal (Paragraph 6) and is on during Apply 1 and Apply 2. To check the oscillator:

(1) Connect the trigger input of the scope to test point WW, using a 10:1 probe.

(2) Set trigger to "external", mode to "AC-HF", slope to "-".

(3) Set Time/Div. to 50 μ Sec, Volts/Div. to 0.5V.

(4) Connect the vertical input to test point U, using a 10:1 probe. The waveform should be as shown in Fig. 11x.

d. The positive and negative supplies for the MOS-IC enter on Pin 1 and Pin 38. If these are not correct refer to Paragraph 8 for Voltage Regulators.

e. Apply + 100 mV dc to the input on the 100 mV range or full-scale on any dc range. Observe the following test points.

Test Point	Test Value	Corrective Action
(W)	Fig. 11b	See Paragraph 9 of this section then check MOS-IC and R69
(WW)	Same as W-0.6V	Check Q32, R68
(V)	Fig. 11c	See Paragraph 2 of this section
(X)	Fig. 11d	Check MOS-IC, R40, R41

Also, with zero input, Apply 2 is on (-13 volts) for less than 50 u s. (Apply -2 is the time for which a DC reference voltage is being applied to the integrator to bring the ramp to zero level, and with zero input the ramp should be zero volts.) If the ramp is not zero, R22 should be readjusted per calibration procedure, or input FET's checked for leakage.

f. Out-3 (pin 29) is the full-scale output which turns the "1" bars of the first tube on (numbering from left to right). If the "1" does not light when the input exceeds full scale (equivalent to 100 mV input on the 100 mV range), check the connection to the tube and IC socket pin connection. If that does not solve the problem, make sure that Yn is on (ground potential) for more than twice the time Apply -1 is on (refer to fig. 11h for wave form). If Yn checks correctly and the "1" bar does not light, the MOS package or tube should be changed.

To obtain polarity signs S1BF5 is tied to +11V on DC volts and DC amps via the range switch. Check Q33, Q36, Q34 and associated circuitry.

g. The output drivers from the MOS-IC package to the seven-segment tubes can be damaged only by the following:

(1) A short across the output connection of the MOS-IC package.

(2) The outputs might be working but the connections to the tube sockets are not making contact. (During the display cycle, and for a lighted bar, the output from the MOS-IC package is + 11 V.)

(3) The outputs might have internal leakage such that the bar does not turn off completely. Replace MOS-IC.

2. Integrator Check

a. With the function switch set to DC V and the range switch set to 100 mV, short the HI and LO input terminals.

b. Set the scope as follows:

(1) Connect trigger input to test point WW, using a 10:1 probe.

(2) Set TIME/DIV to 50 ms, VOLTS/DIV to 0.1 V.

(3) Set scope on EXT. trigger, mode to AC-LF, slope to "-".

(4) Connect vertical input to test point C, using a 10:1 probe. Observe no ramp and DC level is 0. ± 0.5 V.

c. If the above DC level is not as stated, check the following test values at the indicated points:

Test Point	Test Value	Corrective Action
+ 11.5 V supply (E)	+ 11.5 ± 0.2V	See Paragraph 8
-13.0 V supply (EE)	-13.0 to -13.5 V	See Paragraph 8
(DD)	+ 7.5 ± 1.0	Check Q10 and Q7
(CC)	-6.0 ± 1.0	Check Q8
(C)	0 ± 0.5 V	Check Q9 and then Q6 and Q11

If the above values are correct, remove the input short and apply + 100 mV. With the scope set up as in Paragraphs 2b(1), 2b(2) and 2b(3) except set VOLTS/DIV to 0.2V, observe a ramp at point C as shown in figure 11a.

If the ramp is not correct, refer to Paragraphs 4 and 5 of this section for FET switching problems.

3. Comparator Check

a. With the same setup as in Paragraph 2a, check the following test values at the indicated points:

Test Point	Test Value	Corrective Action
(FF)	+ 9.0 ± 1.0	Check Q14 and Q16 and associated resistors
(F)	+ 9.5 ± 1.0	Check Q14 and Q16
(G)	-1.0 to -1.4V	Check Q15, Q17, CR2, CR3, and associated resistors

b. With a + 100 mV applied to the input oscilloscope (setup as in paragraphs 2b(1) and 2b(2), and 2b(3), observe a wave form at test point Y as shown in figure 11n.

If the wave form is not correct, refer to Paragraphs 4 and 5 for FET switching problems.

4. Input and Self-zero Switching

a. With the scope set up as in paragraphs 2b(1), 2b(2), and 2b(3), check the test values at the indicated test points as follows:

Test Point	Test Value	Corrective Action
(A)	Figure 11f	Check Q4 and Q5
(AA)	Figure 11e	Check Q1 and Q2
(B)	Figure 11i	Check Q1 and CR1
(D)	Figure 11p	Check Q12 and Q13

5. Reference FET Switching and Flip-Flop (Megohms Operation)

The flip-flop drives the two reference FETs Q18 and Q19 for the application of + ER and -ER voltages to the integrator. There are three controlling signals going in the flip-flop, plus a gate from the output of the comparator which senses the polarity of the input.

If it is determined that a problem exists in this area, check the following test points:

For Positive Inputs		Corrective Action
(JJ)	-13.0V	Check Q20 and Q21

For Netative Inputs		Corrective Action
(J)	-13.0V	Check Q24 and Q25

The flip-flop outputs are at test points JJ and J. These test points may be checked as follows:

Test Point	Waveform/DC Level	Corrective Action
Set-up + 100 mV input,	on 100 mV dc range	
(JJ)	-13.0V	Q20, Q21
(J)	Figure 11k	Q24, Q25
Set-up -100 mV input,	on 100 mV dc range	
(JJ)	Figure 11 l	Q20, Q21
(J)	-13.0V	Q24, Q25, Q26, Q30

If the flip-flop is working properly, the switching FETs, Q18 and Q19, may be checked by monitoring the voltage at the drain and source. This voltage is the reference voltage which is present only during Apply-2 (except in megohms operation). The source voltage should be +90.9 mV during Apply-2 for positive inputs (Q19 on) and -90.9 mV during Apply-2 for negative inputs (Q18 on). The operation of the reference FET's and flip-flop is identical on all functions except megohms. In megohms the flip-flop is held in the positive polarity state by connecting point JJ to -13.0V via the range switch deck 2A rear. This allows only the positive reference FET, Q19, to be turned on when the output of the flip-flop is gated on via Q44. Apply-1 and Apply-2 are interchanged at points K and BB. The waveform at BB is shown in figure 11j for all functions except megohms. In megohms test point BB will be similar to figure 11i. This signal is generated by Apply-1 and applies the reference to the integrator during Apply-1 which generates a negative ramp at point C.

Test Point	Test Value	Corrective Action
(HH)	Figure 11q	Check Q20, R22 and C12
(H)	Figure 11r	Check Q30, R119 and C42
(I)	Figure 11g	Check Q44 and associated circuitry

For test point I, the time for which the voltage is around ground depends on the dc voltage being applied (with 10 kHz oscillator frequency, 100 mV input on 100 mV range, test point I is at ground for 100 ms).

6. Output Circuitry and YN

YN is the controlling input for the MOS package. When YN is around ground the count starts; YN is on. When YN is + 11 volts the count stops; YN is off. Any time YN is below ground more than -0.7V, replace CR4.

With a negative dc input voltage on the dc volts range the YN drive conditions are:

Q29 off during Apply-2; Q26 and Q28 will turn on when the comparator output is negative. Q22 and Q23 are off.

If the above does not prove to be true, check and correct as needed, so that the YN operation is exactly as above. See also Section V.

7. Function and Range Switching

Check connections carefully. Check for any switch deck that may have been damaged due to excessive current and voltages. If switches are damaged, factory repair is recommended. Check component mountings and lead dress for possible shorts.

8. DC Voltage Regulators

The unregulated dc input voltage may be as follows:

+16.7 to +13.0 V

-16.7 to -13.0 V

The unregulated voltages are switched, by the function switch, to the inputs of the positive and negative regulators. The negative regulator is adjustable by R151 and consists of a low current amplifier and reference element. Q53, 52, and 50 serve as the comparator and amplifier and Q51 the Series Pass element. CR15 is the reference Zener and should be 6.2 V ± 5% when the output of the regulator is sufficient for Zener breakdown.

The positive regulator is referenced to the negative regulated voltage and consists of amplifier transistor Q49 and series pass transistor Q48.

R151 should be adjusted to obtain + 11.5V output on the positive supply at test point E.

9. Reset and Latch Toggle

a. The reset pulse circuitry is located on the reference board. The wave form is shown in Figure 11 u. If problems exist in this area, check Q38, Q39, and associated circuitry. Note that the reset pulse initiates the count sequence within the MOS-IC.

b. The latch toggle is generated by capacitively coupling Apply 2 into Q37 which in turn drives Pin 18 of the MOS-IC. The multimeter may operate properly but not display the readings obtained if this circuitry malfunctions. Figures 11V and 11W show wave forms of the latch toggle signal obtained at test point R.

10. Reference Supply

The negative reference is generated by a highly stable temperature compensated Zener CR13. To conserve power the Zener is turned on only when it is applied to the integrator. Transistor Q46 is turned on by Apply 2 which energizes the constant current generator, Q45. The positive reference is generated by a unity gain inverting amplifier consisting of Q43 and Q44.

The reference supplies may be checked by removing the input to R130 (Apply 2) and connecting this point to the + 11.5 V supply through a 100 k resistor thereby turning on both references at all times.

Test Point	Test Value	Corrective Action
Base of Q45	-0.7 V	Check CR11 and Q46
(S)	-6.3 V ± 5%	Check Q46, CR13, and Q45
(T)	+6.0 V ± 5%	Check Q43, Q44 (Adjust with R127)

If Q46 does not turn on when connected to R130, check signal at base. Note that this signal is Apply 2 and the length of time Q46 is on depends on the length of Apply 2 or the reading obtained (full scale reading $\approx$ 100 m Sec).

11. Power Supply

The batteries are charged by rectifying the ac voltage obtained from a stepdown transformer. The + 14.4 and -14.4 batteries are placed in series for charging. DS 1 serves as a charging indicator and series current limiter. The 1.2V filament battery is charged from a separate rectifier and transformer winding.

12. AC/DC Converter

The time constants in the ac/dc converter will hold the amplifier (A_1) in a saturated condition for several seconds after turn-on; however, if the input is shorted to ground and test point O is not at ground (± 1 V), check the following test points and correct where needed:

Test Point	Test Value	Corrective Action
(M)	+ 11.5V	Connections, switching
(MM)	-13.0 V	Connections, switching
(O)	0.0 + 1 V dc	Readjust R90 and check Q42
(LL)	+ 7.5 V	Check R92, 93
(SS)	Same as input	Z1, CR5, CR6, C35

If the R90 adjustment is not sufficient to bring point O to zero volts (allow time for stabilization) check Q42, Q41, and Q40. If replacement is necessary, use factory selected parts only.

SECTION IX
CALIBRATION

CLEANING PROCEDURE

If the unit to be calibrated has been serviced, it should be cleaned prior to calibration. Brush the circuit board clean of any rosin deposits, using clean "Printed Circuit Cleaner" manufactured by the John B. Moore Company. Dip the boards and switches into a tank of clean Freon TF or Genesolv D for a period of 20 seconds. Remove from this tank and dip immediately into a tank of Freon TF or Genesolv D with two parts of Dow Corning DC200 silicon oil added.

RECOMMENDED CALIBRATION EQUIPMENT

Hewlett-Packard 740B dc Standard and Differential Voltmeter.

Hickok DP110 Microvoltmeter with Hickok Model 3202 Digital Main Frame.

Hickok DP130 ac Voltmeter calibrated for 100% overrange, with Hickok Model 3202 Main Frame.

Krohn-Hite Model 4200 Sine Wave Oscillator.

General Radio Model 1433H Resistor Standard Box, 1 Ohm to 11 Megohms, 0.02%.

DC Current Generator, capable of supplying 0.1 mA to 1A ± 0.02%.

Hickok Model 5000 or Model 5002 Oscilloscope.

CALIBRATION PROCEDURE

With the recommended calibration equipment, the multimeter inputs should be monitored to the given accuracy (unless the equipment being used is guaranteed to be within that accuracy). Ambient temperature should be 23°C ± 1°C.

NOTE

This procedure must be followed in sequential order. Do not attempt to calibrate any section until all previous sections have been calibrated or verified.

1. Voltage Regulators

Turn the multimeter on and make the following measurements using the DP110 Voltmeter.

a. Measure voltage between test point E and ground. A reading of + 11.5 V ± 0.1 V should be obtained. If necessary adjust R151 for proper reading.

b. Measure voltage between test point EE and ground. A reading between -13.0V and -13.5V should be obtained.

2. Zero and Ohms

a. Set function switch to OHMS, range switch to 100K range. Set calibration controls R2 and R108 to center position.

b. Connect multimeter to decade resistor box set to 1.00 KΩ.

c. Adjust R22 for a reading of 01.0 ± 00.0.

d. Set decade resistor to 1.06 K Ω and check display for 01.1. Readjust R22 if necessary.

e. Set decade resistor to 0.94 K Ω and check display for 00.9. Readjust R22 if necessary.

f. Repeat c, d and e to verify the setting of R22; readjust if necessary.

3. Ohms

a. Set function switch to OHMS and range switch to 10K range.

b. Connect multimeter to decade resistor set to 10.00 KΩ.

c. Adjust R108 for a display of 9.98 ± 0.00. (Note: full scale on ohms must be adjusted to 998 to center non-linearity of divider.)

d. Set range switch to 10 M ohm and apply 10 MΩ to input. Adjust R102 for a display of 10.00 ± 0.03.

e. Apply 10 K Ω to input. Adjust R79 for a display of 0.01 ± 0.00.

f. Short HI to LO and check for zero ± 1 digit on all ranges and functions.

4. DC Volts

a. Set function switch to DC VOLTS, range switch to 100 mV range.

b. Apply + 190.00 mV and adjust R127 to display + 190.0 ± 00.1.

c. Set range switch to 1V range and apply + 1.9000V. Adjust R2 to display 1.900 ± 0.001.

d. Repeat b and c as these adjustments are interacting.

e. Set range switch to 100 mV range and apply -190.00 mV. Adjust R124 to display -190.0 ± 00.1.

f. Check 10V, 100V and 1KV ranges to insure accuracy.

5. AC Volts

a. Set function switch to AC V, range switch to 100 mV.

b. Connect HI terminal to LO. With 10:1 scope probe connected to test point O, adjust R90 for a dc level of 0 ± 1V. (Allow time for stabilization.)

c. Calibrate individual ranges by the following table:

Range	Input Voltage 2.5 Khz	Adjust
100mV	190.0mV	R106
1V	1.900V	R116
10V	19.00V	R117
100V	190.0V	R118
1KV	1.000KV	R119

d. Check all ranges for proper accuracy (refer to Section II) at 22 Hz, 50 Hz and 100 kHz. Maximum input frequency on 1KV range is 10 kHz.

6. Current

There is no current calibration. However, all ranges should be checked to insure that shunts are in tolerance.

SECTION X
PARTS LIST
MODEL 3300B

When ordering parts be sure to give the reference designation, description, and the Hickok part number as listed in the following table. Also include the model and serial number of the equipment. There is a minimum billing charge of $5.00 for all parts orders.

SYMBOL	NOTES	DESCRIPTION	CODE NO.
BT1		BATTERY ASSEMBLY: + 14.40, 0, -14.4 volts	2210-45
BT2		BATTERY: nk. cadmium, 1.25 volts	2210-46
C1		CAPACITOR, FIXED, DIPPED MICA: 22 pf, 5%, 500 volts	3096-509
C2		CAPACITOR, FIXED, POLYCARBONATE: 0.01 uf, 10%, 630 volts	3092-601
C3		CAPACITOR, FIXED, POLYCARBONATE: 0.10 uf, 10%, 400 volts	3092-413
C4		CAPACITOR, FIXED, CERAMIC: 220 pf, 20%, 500 volts	3111-518
C5		CAPACITOR, FIXED, DIPPED MICA: 270 pf, 5%, 500 volts	3096-535
C6		CAPACITOR, FIXED, DIPPED MICA: 390 pf, 5%, 500 volts	3096-539
C7		CAPACITOR, FIXED, POLYESTER FILM: 2.2 uf, 20%, 100 volts	3103-81
C8		CAPACITOR, FIXED, POLYCARBONATE: 0.047 uf, 10%, 400 volts	3092-409
C9		CAPACITOR, FIXED, DIPPED MICA: 100 pf, 5%, 500 volts	3096-525
C10		CAPACITOR, FIXED CERAMIC: 1000 pf, +50%, -20%, 500 volts	3111-522
C11		CAPACITOR, FIXED, DIPPED MICA: 150 pf, 5%, 500 volts	3096-529
C12		CAPACITOR, FIXED, POLYESTER FILM: 0.22 uf, 20%, 100 volts	3103-80
C13		Same as C12	
C14		Same as C4	
C15		Same as C5	
C16		Not used	
C17		Same as C11	
C18		CAPACITOR, FIXED, POLYESTER FILM: 0.1 uf, 20%, 100 volts	3103-78
C19		CAPACITOR, FIXED, CERAMIC: 2200 pf, +50%, -20%, 500 volts	3111-524
C20		CAPACITOR, FIXED, POLYSTYRENE: 150 pf, 5%, 630 volts	3103-99
C21		CAPACITOR, FIXED, POLYSTYRENE: 160 pf, 5%, 630 volts	3103-100
C22		Same as C21	
C23		CAPACITOR, FIXED, POLYSTYRENE: 430 pf, 5%, 160 volts	3103-102
C24		CAPACITOR, FIXED, POLYSTYRENE: 4700 pf, 5%, 30 volts	3103-101
C25		CAPACITOR, FIXED, POLYSTYRENE: 0.047 uf, 5%, 30 volts	3103-98
C26		CAPACITOR, FIXED, POLYSTYRENE: 0.47 uf, 5%, 30 volts	3103-97
C27		Same as C10	
C28		Same as C12	
C29		Same as C18	
C30		Same as C18	
C31		Same as C18	
C32		Same as C9	
C33		CAPACITOR, FIXED, COMPOSITION: 3.9 pf, 10%, 500 volts	3116-10
C34		Same as C18	
C35		CAPACITOR, FIXED, METALLIZED POLYESTER FILM: 1.0 uf, 10%, 63 volts	3103-58

SYMBOL	NOTES	DESCRIPTION	CODE NO.
C36		Same as C35	
C37		Same as C10	
C38		Same as C19	
C39		Same as C11	
C40		Same as C9	
C41		CAPACITOR, FIXED, POLYCARBONATE: 0.022 uf, 10%, 400 volts	3092-405
C42		CAPACITOR, FIXED, ELECTROLYTIC: 100 uf, +70%, -20%, 70 volts	3085-393
C43		Not used	
C44		CAPACITOR, FIXED, CERAMIC: 3300 pf, +50 -20%, 500 volts	3111-525
C45		Same as C10	
CR1		SEMICONDUCTOR DEVICE: diode 1N914	3870-175
CR2		Same as CR1	
CR3		Same as CR1	
CR4		Same as CR1	
CR5		SEMICONDUCTOR DEVICE: diode-hot carrier	3870-226
CR6		Same as CR5	
CR7		Same as CR1	
CR8		Same as CR1	
CR9		Same as CR1	
CR10		Same as CR1	
CR11		Same as CR1	
CR12		SEMICONDUCTOR DEVICE: zener diode 1N5731B	3870-302
CR13		SEMICONDUCTOR DEVICE: diode 1N823A	3870-225
CR14		Same as CR1	
CR15		Same as CR12	
CR16		SEMICONDUCTOR DEVICE: diode 1N2069	3870-62
CR17		Same as CR16	
CR18		Same as CR1	
CR19		Same as CR1	
CR20		Same as CR1	
CR21		Same as CR1	
CR22		Same as CR1	
CR23		Same as CR1	
CR24		Same as CR1	
CR25		Same as CR1	
CR26		Same as CR1	
CR27		Same as CR1	
CR28		Same as CR1	
CR29		Same as CR1	
CR30		Same as CR1	
DS1		LAMP: 28 volt, 40 ma, with blue lens and 6 in. leads	12270-116
DS2		LAMP, SOLID STATE: LED type MV5025	
DS3		Same as DS2	
F1		FUSE: 1/4 amp, pigtail, 250 V, SLO-BLO	6900-76
J1		CONNECTOR: 7 pin	3475-202
P1		PLUG: 6 prong	16525-218
Q1		TRANSISTOR: 2N5139 PNP silicon	20861-181
Q2		TRANSISTOR: FET N -Channel, selected	20861-301
Q3		TRANSISTOR: silicon planar field effect N-Channel	20861-252
Q4		Same as Q3	
Q5		TRANSISTOR: 2N5133 NPN	20861-210
Q6		TRANSISTOR: FET N-Channel, selected	20861-253
Q7		Same as Q5	
Q8		Same as Q5	
Q9		TRANSISTOR: 2N4248 PNP	20861-268
Q10		Same as Q5	
Q11		Same as Q6	
Q12		TRANSISTOR: 2N3566 NPN silicon	20861-122
Q13		Same as Q3	
Q14		Same as Q9	
Q15		Same as Q5	
Q16		Same as Q9	
Q17		Same as Q5	

SYMBOL	NOTES	DESCRIPTION	CODE NO.
Q18		Same as Q3	
Q19		Same as Q3	
Q20		TRANSISTOR: NPN silicon type A139	20861-316
Q21		Same as Q20	
Q22		Same as Q5	
Q23		Same as Q5	
Q24		Same as Q20	
Q25		Same as Q20	
Q26		Same as Q1	
Q27		Same as Q5	
Q28		Same as Q5	
Q29		Same as Q5	
Q30		Same as Q5	
Q31		Not used	
Q32		Same as Q12	
Q33		TRANSISTOR: 2N5305	20861-267
Q34		Same as Q9	
Q35		Same as Q5	
Q36		Same as Q5	
Q37		Not used	
Q38		Same as Q1	
Q39		Same as Q33	
Q40		TRANSISTOR: FET N-Channel, selected	20861-254
Q41		TRANSISTOR: FET N-Channel, selected	20861-255
Q42		Same as Q41	
Q43		TRANSISTOR: differential pair NPN silicon	20861-117
Q44		Same as Q1	
Q45		Same as Q5	
Q46		Same as Q1	
Q47		Same as Q1	
Q48		Same as Q33	
Q49		Same as Q5	
Q50		Same as Q1	
Q51		TRANSISTOR: 2N6013 PNP	20861-309
Q52		Same as Q5	
Q53		Same as Q1	
R1		RESISTOR, FIXED, METAL FILM: 8.87 megohms, 1%, 2 watt	18575-614
R2		RESISTOR, VARIABLE: composition, 300 K ohms, 20%, linear taper	16925-721
R3		RESISTOR, FIXED, METAL FILM: 900 K ohms, 0.05%, 1/2 watt	18526-134
R4		RESISTOR, FIXED, METAL FILM: 90 K ohms, 0.05%, 1/2 watt	18526-135
R5		RESISTOR, FIXED, METAL FILM: 9 K ohms, 0.05%, 1/2 watt	18526-136
R6		RESISTOR, FIXED, METAL FILM: 1 K ohms, 0.05%, 1/2 watt	18526-137
R7		RESISTOR, FIXED: calibration, value determined in production	
R8		RESISTOR, FIXED, WIRE WOUND: 0.1000 ohms, +1%, -0%, 3 watt	18575-615
R9		RESISTOR, FIXED: calibration, value determined in production	
R10		RESISTOR, FIXED, WIRE WOUND: 1.00 ohms, ± 1%, -0%, 3 watt	18575-616
R11		RESISTOR, FIXED, WIRE WOUND: 10 ohms, 0.1%, 1 watt	18550-236
R12		RESISTOR, FIXED, METAL FILM: 100 ohms, 0.1%, 1/2 watt	18526-133
R13		RESISTOR, FIXED, METAL FILM: 1 megohm, 0.25%, 1/2 watt	18526-138
R14		RESISTOR, FIXED, COMPOSITION: 20 megohms, 5%, 1/4 watt	18456-201
R15		RESISTOR, FIXED, COMPOSITION: 8.2 megohms, 5%, 1/4 watt	18455-821
R16		RESISTOR, FIXED, DEPOSITED CARBON: 270 K ohms, 5%, 1/4 watt	18470-274
R17		RESISTOR, FIXED, DEPOSITED CARBON: 3 K ohms, 5%, 1/4 watt	18470-302
R18		RESISTOR, FIXED, METAL FILM: 11.5 K ohms, 1%, 1/4 watt	18555-81
R19		RESISTOR, FIXED, METAL FILM: 1.13 megohms, 1%, 1/4 watt	18555-164
R20		RESISTOR, FIXED, DEPOSITED CARBON: 620 K ohms, 5%, 1/4 watt	18470-624
R21		RESISTOR, FIXED, DEPOSITED CARBON: 10 K ohms, 5%, 1/4 watt	18470-103

SYMBOL	NOTES	DESCRIPTION	CODE NO.
R22		RESISTOR, VARIABLE: composition, 3 K ohms, 20%, linear taper	16925-700
R23		RESISTOR, FIXED, DEPOSITED CARBON: 150 K ohms, 5%, 1/4 watt	18470-154
R24		Same as R16	
R25		RESISTOR, FIXED, DEPOSITED CARBON: 18 K ohms, 5%, 1/4 watt	18470-183
R26		RESISTOR, FIXED, DEPOSITED CARBON: 39 K ohms, 5%, 1/4 watt	18470-393
R27		Same as R21	
R28		RESISTOR, FIXED, DEPOSITED CARBON: 8.2 K ohms, 5%, 1/4 watt	18470-822
R29		RESISTOR, FIXED, DEPOSITED CARBON: 6.8 K ohms, 5%, 1/4 watt	18470-682
R30		RESISTOR, FIXED, DEPOSITED CARBON: 91 K ohms, 5%, 1/4 watt	18470-913
R31		RESISTOR, FIXED, DEPOSITED CARBON: 47 K ohms, 5%, 1/4 watt	18470-473
R32		RESISTOR, FIXED, DEPOSITED CARBON: 27 K ohms, 5%, 1/4 watt	18470-273
R33		Same as R28	
R34		RESISTOR, FIXED, DEPOSITED CARBON: 75 K ohms, 5%, 1/4 watt	18470-753
R35		RESISTOR, FIXED, DEPOSITED CARBON: 220 K ohms, 5%, 1/4 watt	18470-224
R36		Same as R21	
R37		RESISTOR, FIXED, DEPOSITED CARBON: value determined in production	
R38		RESISTOR, FIXED, DEPOSITED CARBON: 4.7 K ohms, 5%, 1/4 watt	18470-472
R39		RESISTOR, FIXED, DEPOSITED CARBON: 1 megohm, 5%, 1/4 watt	18470-105
R40		RESISTOR, FIXED, DEPOSITED CARBON: 3.9 K ohms, 5%, 1/4 watt	18470-392
R41		RESISTOR, FIXED, DEPOSITED CARBON: 62 K ohms, 5%, 1/4 watt	18470-623
R42		Same as R21	
R43		Same as R21	
R44		Same as R26	
R45		Same as R17	
R46		Same as R21	
R47		Same as R29	
R48		RESISTOR, FIXED, DEPOSITED CARBON: 24 K ohms, 5%, 1/4 watt	18470-243
R49		RESISTOR, FIXED, METAL FILM: 549 ohms, 0.5%, 1/4 watt	18555-146
R50		RESISTOR, FIXED, DEPOSITED CARBON: 22 K ohms, 5%, 1/4 watt	18470-223
R51		Same as R50	
R52		Same as R21	
R53		Same as R35	
R54		Same as R21	
R55		RESISTOR, FIXED, DEPOSITED CARBON: 360 K ohms, 5%, 1/4 watt	18470-364
R56		Same as R35	
R57		RESISTOR, FIXED, DEPOSITED CARBON: 100 K ohms, 5%, 1/4 watt	18470-104
R58		RESISTOR, FIXED, DEPOSITED CARBON: 470 K ohms, 5%, 1/4 watt	18470-474
R59		Same as R32	
R60		Same as R21	
R61		Same as R50	
R62		RESISTOR, FIXED, DEPOSITED CARBON: 33 K ohms, 5%, 1/4 watt	18470-333
R63		Same as R57	
R64		Same as R21	
R65		Same as R35	
R66		RESISTOR, FIXED, DEPOSITED CARBON: 15 K ohms, 5%, 1/4 watt	18470-153
R67		Same as R50	
R68		Same as R32	
R69		RESISTOR, FIXED, DEPOSITED CARBON: 56 K ohms, 5%, 1/4 watt	18470-563
R70		RESISTOR, FIXED, DEPOSITED CARBON: 4.3 K ohms, 5%, 1/4 watt	18470-432
R71		Same as R69	
R72		RESISTOR, FIXED, DEPOSITED CARBON: 20 K ohms, 5%, 1/4 watt	18470-203
R73		Same as R39	
R74		Not used	
R75		Same as R16	
R76		RESISTOR, FIXED, DEPOSITED CARBON: 330 K ohms, 5%, 1/4 watt	18470-334
R77		Same as R57	
R78		RESISTOR, FIXED, DEPOSITED CARBON: 3.3 K ohms, 5%, 1/4 watt	18470-332
R79		RESISTOR, VARIABLE: composition, 1 megohm, 20%, linear taper	16925-755
R80		Not used	
R81		RESISTOR, FIXED, DEPOSITED CARBON: 510 K ohms, 5%, 1/4 watt	18470-514
R82		Same as R57	

SYMBOL	NOTES	DESCRIPTION	CODE NO.
R83		RESISTOR, FIXED, COMPOSITION: 3 megohms, 5%, 1/4 watt	18455-301
R84		RESISTOR, FIXED, DEPOSITED CARBON: 2 K ohms, 5%, 1/4 watt	18470-202
R85		RESISTOR, FIXED, COMPOSITION: 6.8 megohms, 5%, 1/4 watt	18455-681
R86		Same as R40	
R87		Same as R35	
R88		Same as R31	
R89		RESISTOR, FIXED, COMPOSITION: 100 megohms, 10%, 1/2 watt	18417-102
R90		Same as R22	
R91		RESISTOR, FIXED, DEPOSITED CARBON: 560 ohms, 5%, 1/4 watt	18470-561
R92		RESISTOR, FIXED, COMPOSITION: 10 megohms, 5%, 1/4 watt	18456-101
R93		Same as R92	
R94		Same as R89	
R95		Same as R89	
R96		Same as R92	
R97		RESISTOR, FIXED, DEPOSITED CARBON: 1.5 K ohms, 5%, 1/4 watt	18470-152
R98		Same as R26	
R99		RESISTOR, FIXED, DEPOSITED CARBON: 12 K ohms, 5%, 1/4 watt	18470-123
R100		RESISTOR, FIXED, METAL FILM: 6.81 K ohms, 1%, 1/4 watt	18554-81
R101		RESISTOR, FIXED, METAL FILM: 453 ohms, 1%, 1/4 watt	18554-79
R102		RESISTOR, VARIABLE: composition, 2.5 megohms, 20%, linear taper	16925-748
R103		RESISTOR, FIXED, COMPOSITION: 2.2 megohms, 10%, 1/4 watt	18455-222
R104		RESISTOR, FIXED, METAL FILM: 11.3 K ohms, 1%, 1/4 watt	18554-78
R105		Same as R100	
R106		RESISTOR, VARIABLE: composition, 1 K ohms, 20%, linear taper	16925-754
R107		Same as R76	
R108		Same as R22	
R109		RESISTOR, FIXED, METAL FILM: 48.7 K ohms, 0.5%, 1/4 watt	18555-147
R110		RESISTOR, FIXED, METAL FILM: 2.15 K ohms, 1%, 1/4 watt	18555-168
R111		RESISTOR, FIXED: calibration, value determined in production	
R112		RESISTOR, FIXED: calibration, value determined in production	
R113		RESISTOR, FIXED: calibration, value determined in production	
R114		RESISTOR, FIXED: calibration, value determined in production	
R115		RESISTOR, FIXED: calibration, value determined in production	
R116		RESISTOR, VARIABLE: composition, 100 ohms, 20%, linear taper	16925-756
R117		Same as R116	
R118		Same as R116	
R119		Same as R116	
R120		Same as R35	
R121		Same as R35	
R122		RESISTOR, FIXED, METAL FILM: 5.40 K ohms, 0.5%, 1/4 watt	18555-177
R123		RESISTOR, FIXED, METAL FILM: 32.3 K ohms, 0.5%, 1/4 watt	18555-149
R124		Same as R22	
R125		RESISTOR, FIXED: calibration, value determined in production	
R126		RESISTOR, FIXED, METAL FILM: 5.36 K ohms, 1%, 1/4 watt	18554-109
R127		RESISTOR, VARIABLE: composition, 300 ohms, 10%, linear taper	16925-769
R128		RESISTOR, FIXED: calibration, value determined in production	
R129		Same as R21	
R130		Same as R21	
R131		RESISTOR, FIXED, DEPOSITED CARBON: 6.2 K ohms, 5%, 1/4 watt	18470-622
R132		Same as R34	
R133		Same as R62	
R134		RESISTOR, FIXED, DEPOSITED CARBON: 560 K ohms, 5%, 1/4 watt	18470-564
R135		RESISTOR, FIXED, DEPOSITED CARBON: 2.7 K ohms, 5%, 1/4 watt	18470-272
R136		RESISTOR, FIXED, DEPOSITED CARBON: 1200 ohms, 5%, 1/4 watt	18470-122
R137		Same as R50	
R138		Same as R50	
R139		Same as R35	
R140		Same as R35	
R141		Same as R57	
R142		Same as R55	
R143		RESISTOR, FIXED, DEPOSITED CARBON: 2.2 K ohms, 5%, 1/4 watt	18470-222

SYMBOL	NOTES	DESCRIPTION	CODE NO.
R144		Same as R57	
R145		RESISTOR, FIXED, METAL FILM: 100 K ohms, 1%, 1/4 watt	18555-37
R146		RESISTOR, FIXED, METAL FILM: 124 K ohms, 1%, 1/4 watt	18555-89
R147		Same as R99	
R148		Same as R50	
R149		Same as R41	
R150		RESISTOR, FIXED, DEPOSITED CARBON: 68 K ohms, 5%, 1/4 watt	18470-683
R151		RESISTOR, VARIABLE: composition, 25 K ohms, 20%, linear taper	16925-753
R152		Same as R69	
R153		Same as R57	
R154		Same as R55	
R155		RESISTOR, FIXED, METAL FILM: 1 K ohms, 0.1%, 1/2 watt	18526-141
R156		Same as R39	
R157		Same as R136	
R158, R159		RESISTOR, FIXED, DEPOSITED CARBON: 1 K ohms, 5%, 1/4 watt	18470-102
R160		RESISTOR, FIXED, WIRE WOUND: 1.9 ohms, 5%, 7 watt	18575-571
R161		RESISTOR, FIXED, COMPOSITION: 620 ohms, 5%, 1 watt	18421-621
R162		Same as R16	
R163		Same as R50	
R164		Same as R39	
R165		Same as R39	
R166		Same as R57	
R167		RESISTOR, FIXED, DEPOSITED CARBON: 3.3 ohms, 5%, 1/4 watt	18555-94
R168		Same as R167	
S1		SWITCH: rotary, function	19912-666
S2		SWITCH: rotary, range	19912-667
T1		TRANSFORMER	20800-387
V1		TUBE: display 7 segment, type N-8063B	20875-292
V2		Same as V1	
V3		Same as V1	
V4		Same as V1	
W1		CORD: type SPT-1, 6 ft. long, 41/34 stranding size 0.300 x 0.110, with molded plug on one end, 2 in. stripped on other end, grey	3675-49
X1		SOCKET: 6 pin	19350-458
Z1		INTEGRATED CIRCUIT: operational amplifier	9800-42
Z2		INTEGRATED CIRCUIT: dual in-line package, 40 pin	9800-55

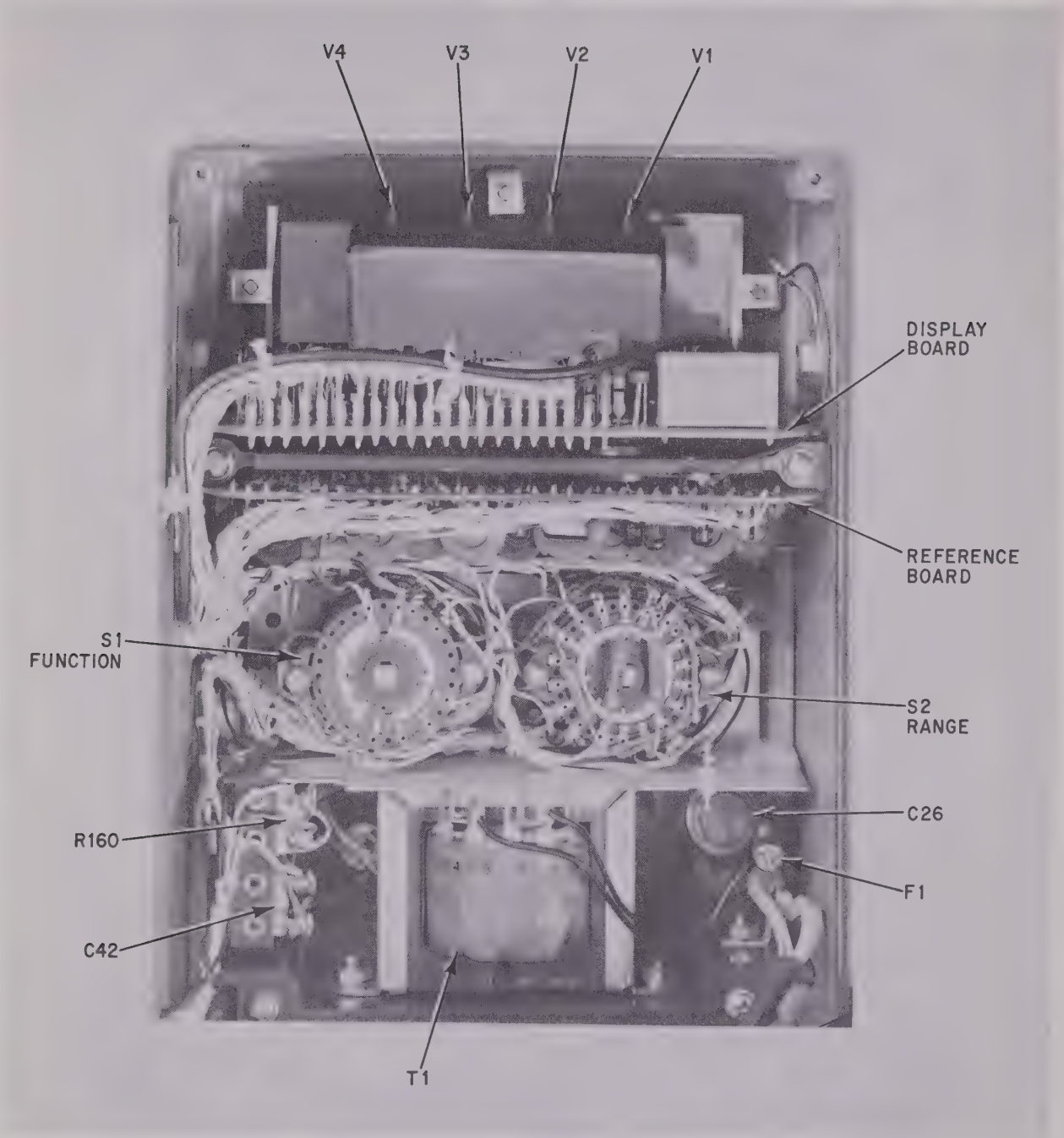


Figure 12. Model 3300B, Rear Cover Removed, Parts Location

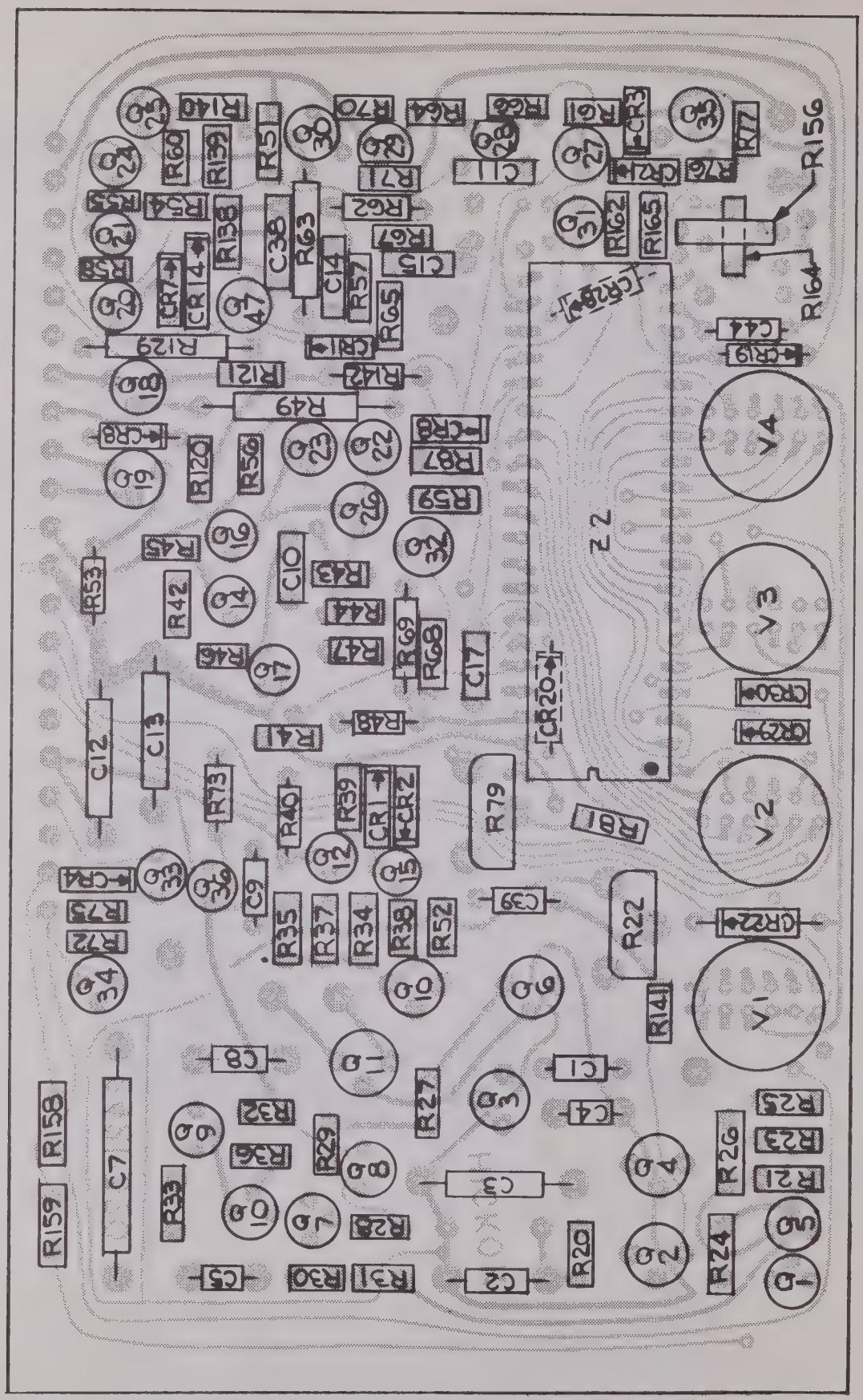


Figure 13 . Model 3300B, Display Board, Parts Locations

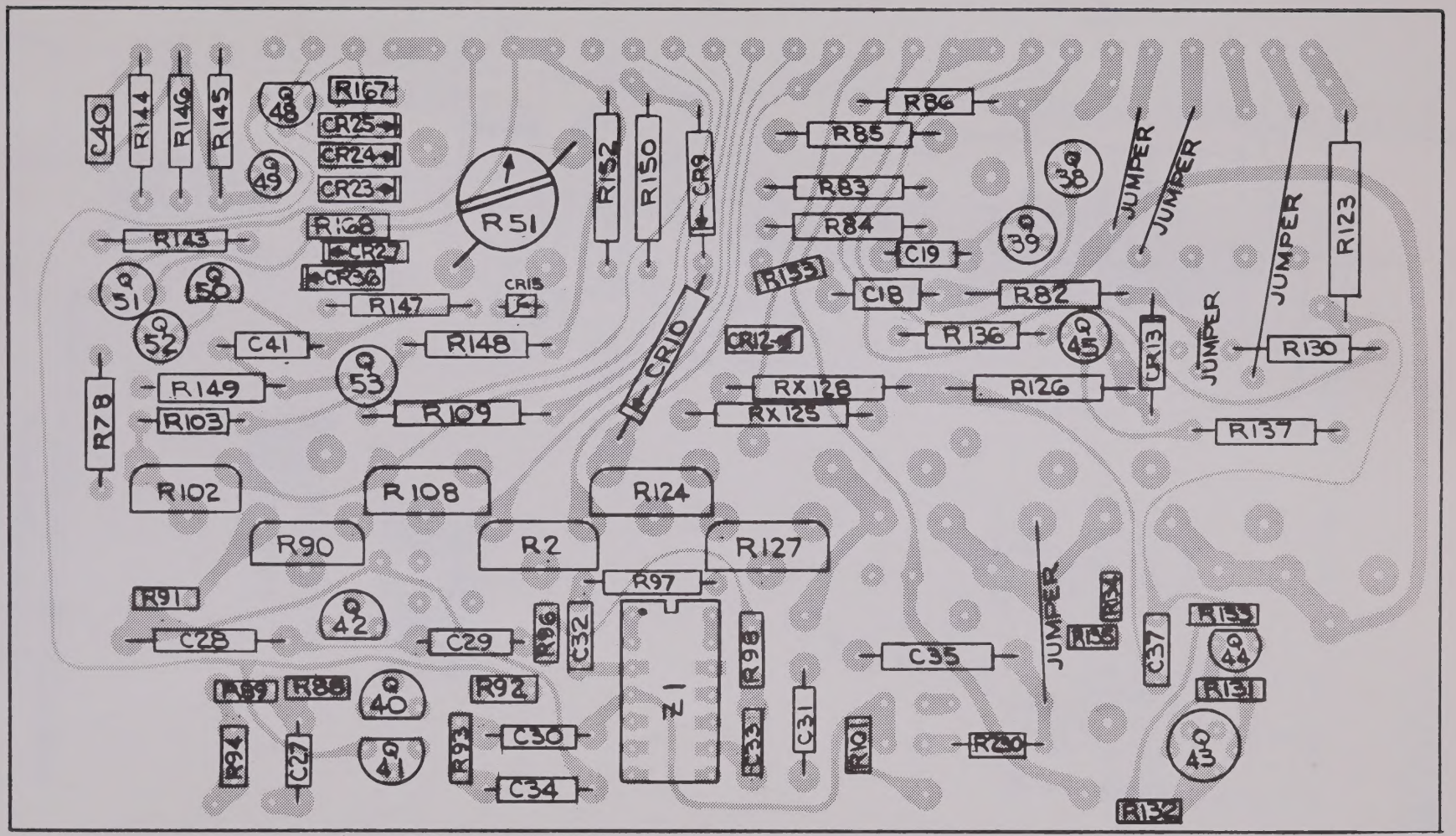


Figure 14. Model 3300B, Reference Board, Parts Location